NASA - TM - 102,645

NASA-TM-102645
19930015338

NASA Technical Memorandum 102645
AVSCOM Technical Memorandum 90-B-010

INFLOW MEASUREMENTS MADE WITH A LASER VELOCIMETER ON A HELICOPTER MODEL IN FORWARD FLIGHT

Volume XI: RECTANGULAR PLANFORM BLADES AT AN ADVANCE RATIO OF 0.30, 0.75 CHORD ABOVE THE TIP PATH PLANE

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Inflow Measurements Made With a Laser Velocimeter on a Helicopter Model in Forward Flight Volume XI: Rectangular Planform Blades at an Advance Ratio of 0.30, 0.75 Chord Above the Tip Path Plane

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SUMMARY

An experimental investigation was conducted in the 14- by 22-Foot Subsonic Tunnel at NASA Langley Research Center to measure the inflow into a scale model helicopter rotor in forward flight (μ = 0.30). The measurements were made with a two-component Laser Velocimeter (LV) 0.75 chord above the plane formed by the path of the rotor tips (tip-path-plane). A conditional sampling technique was employed to determine the position of the rotor at the time that each velocity measurement was made so that the azimuthal fluctuations in velocity could be determined. Measurements were made at a total of 180 separate locations in order to clearly define the inflow character. The mean and standard deviation of the induced inflow ratios and the azimuthally dependent induced inflow ratios are included on 5.25 flexible disk in the pocket on the inside of the rear cover of this report. These data are presented herein without analysis.

INTRODUCTION

One of the problems confronting the helicopter industry is the lack of detailed information about the velocity fluctuations around and through rotating blades. This information is needed for two reasons: to ensure a more complete understanding of the flow field environment associated with a thrusting rotor and to provide data for the validation of rapidly emerging computational codes. One explanation for the lack of available data is the absence, until recent years, of a suitable device for making

such measurements. Making measurements of the velocity around a system of rotating blades requires an accurate, nonintrusive measurement capability that presents a minimum risk to the systems involved. The Laser Velocimeter (LV), which uses high energy light beams to measure velocities, is ideally suited to this task.

The Laser Velocimeter has been successfully used to measure specific areas and localized phenomena within the rotor disk (references 1 thru 3). In addition, the hotwire anemometer and pressure probe, both having directional measuring limitations, have been employed in similar programs (references 4 and 5). This comprehensive investigation has been conducted to measure the flow into a representative rotor system as a function of azimuth using a two-component (streamwise and vertical direction) LV system.

NOTATION

A	rotor disc area, (πR^2), ft^2
A_0	Constant term in Fourier series of blade feathering (collective) at r/R = 0.75, deg
A_1	Coefficient of cosine term in Fourier series of blade feathering, deg
b	Number of blades
B_1	Coefficient of sine term in Fourier series of blade feathering, deg
C_Q	Rotor torque coefficient, $Q/(\rho A(12R)V_{tip}^2)$, nondimensional
C_D	Rotor drag coefficient, $D/(\rho A\ V_{tip}^2)$, nondimensional
C_T	Rotor thrust coefficient, $T/(\rho A\ V_{tip}^2)$, nondimensional
D	Rotor drag, lbf (positive to the rear)
q	Dynamic pressure, lb/ft^2
Q	Rotor torque, in-lbf
r	Local radius of the rotor system, ft
R	Rotor radius, ft
T	Thrust produced by the rotor, lbf
U	Freestream component of velocity, ft/sec, (positive downstream)

u_i Induced component of velocity parallel to the tip path plane, ft/sec, (positive downstream)

V Vertical component of velocity, ft/sec, (positive up)

v_i Induced component of velocity normal to the tip path plane, ft/sec, (positive up)

V_{tip} Rotor blade hover-tip velocity, ft/sec, (ΩR)

V_∞ Tunnel freestream velocity, ft/sec, (positive downstream)

SYMBOLS

α Angle between rotor disk and freestream velocity (positive nose up), deg

λ Inflow Ratio normal to tip path plane (positive up), $(V_\infty \sin \alpha + v_i)/V_{tip}$

λ_i Induced Inflow Ratio normal to tip path plane (postive up), v_i/V_{tip}

μ_∞ Rotor advance ratio, $V_\infty \cos \alpha/V_{tip}$

μ Inflow Ratio parallel to tip path plane (positive downstream), $(V_\infty \cos \alpha + u_i)/V_{tip}$

μ_i Induced Inflow Ratio parallel to tip path plane (positive downstream), u_i/V_{tip}

Ω Rotor rotational speed, radians/sec

ψ Rotor azimuth measured from downstream position, positive counterclockwise, as viewed from above, deg

ρ Air density, slug/ft^3

θ Blade pitch angle at a specific azimuth (positive nose up), deg, $\theta = A_0 - A_1 \cos \psi - B_1 \sin \psi$

$\overline{xx}$ Mean value

EXPERIMENTAL APPARATUS

The experimental apparatus used in this investigation included the NASA Langley Research Center 14- by 22-Foot Subsonic Tunnel, the 2-Meter Rotor Test System (2MRTS), and a two-component laser velocimeter system.

The 14- by 22-Foot Subsonic Tunnel is an atmospheric, closed-circuit wind tunnel of conventional design with enhancements for the testing of powered and high-lift

configurations (reference 6). The tunnel is pictured in figure 1 and shown schematically in figure 2. When the tunnel is operated in the open configuration, the walls and ceiling of the test section are lifted out of the flow, leaving only a solid floor and a flow collector. In this configuration, the tunnel can be driven to about 170 knots. This investigation was conducted with the tunnel in the open configuration to allow complete optical access to the rotor flow field.

The 2MRTS is a general purpose rotorcraft model testing system which was mounted on a strut in the forward part of the test section (see figure 3). The system consists of a 29-horsepower electric drive motor and 90 degree speed-reducing transmission, a blade pitch remote control system, and two six-component strain gage balances used for measuring forces and moments on the rotor system and the generic fuselage shell (ROBIN). The four-bladed rotor hub is fully articulated with viscous dampers for lead-lag motion and coincident flap and lag hinges. A more detailed description of the 2MRTS and the ROBIN fuselage can be found in reference 7. The characteristics of the rotor blades used during this investigation can be found in table 1. No attempt was made to dynamically scale the rotor blades; rather, they were very rigid to minimize blade aeroelastic response uncertainties.

The LV system used in this investigation was designed to measure the instantaneous components of velocity in the longitudinal (freestream) and vertical directions. The LV system is described in reference 8. The system is comprised of four subsystems: optics, traverse, data acquisition, and seeding. The optics subsystem, which is shown in figure 4, operates in backscatter mode and at high power (3 watts in all lines) in order to accommodate the long focal lengths needed to scan the wide test section. The transmitting and receiving optics packages are augmented by a zoom lens system consisting of a 3-inch clear aperture negative lens and a 12-inch clear aperture positive lens. Bragg cells in each of the optical paths provide a directional measurement capability. The velocity measurements are made at a point in space where the four beams cross, called the sample volume. The length of the sample volume (transverse to the flow direction) increases as the sample volume is moved away from the optics assembly. The sample volume length, over the 10- to 20 foot focal length of the system, is less than 1 cm and has a nearly constant diameter of 0.2 mm.

The traverse subsystem provides five degrees of freedom in positioning the sample volume and is controlled by the same computer that is used for data acquisition.

Translation of the sample volume in the horizontal and vertical direction is accomplished by displacing the entire optics platform. Translation along the lateral axes is accomplished by displacing the negative lens located in the zoom lens assembly, thus refocusing the sample volume along the axis of optical transmission. The other two degrees of freedom, pan and tilt, are implemented by rotating the final mirror about its vertical and horizontal axes in order to change the direction of optical transmission. The total range of the traversing system is 7 feet vertically, 6 feet streamwise, 16.5 feet laterally, and 10° in both pan and tilt. Measurements can be made outside of this envelope by re-positioning the optics platform, which is mounted on wheels to facilitate such relocations. For this study the traversing system was positioned to the right of the test section when looking upstream as shown in figure 3.

The data acquisition subsystem is shown schematically in figure 5 and interfaces with the optical signal processing equipment to receive two channels of raw LV data and up to five channels of auxiliary data. In this investigation, two of the auxiliary channels were used for the acquisition of data relative to blade position (one each for the U and V components). The system converts the raw LV data to engineering units and determines the statistical characterstics of the acquired data so that the test results can be evaluated during the acquisition process. The raw data and 64 parameters from the tunnel static data acquisition system are written to magnetic tape for later analysis. The final function performed by the data system is to control the five degree-of-freedom scan system.

The seeding subsystem, shown schematically in figure 6 and in the photo in figure 7, is a solid particle, liquid dispensing system (reference 9). Polystyrene latex microspheres are suspended in a mixture containing, by volume, 50 percent distilled water and 50 percent ethyl alcohol. The advantages of the polystyrene particles are their low density, high reflectivity, and precise particle size. The particles used in this investigation were 1.7 microns in diameter with a standard deviation of 0.0239 microns. The particle mixture is pumped to an array of nozzles where compressed air is used to atomize the mixture. These nozzles are mounted on a frame in the settling chamber of the tunnel; the position of the frame is remotely controlled by the laser operator during the data acquisition process. The low vapor pressure of water/alcohol mixture allows it to evaporate as it travels the 85 feet from the settling chamber to the test section. This process provides isolated single particles in the flow

field whose velocities are measured as they pass through the sample volume. The local fluid velocity is inferred from the seed particle velocity.

ERROR ANALYSIS

The overall LV system error is obtained by summing the the error of all of the components that contribute to an error in the velocity measurement. The error sources are summarized the table below, and are defined in references 10 and 11. The resulting total bias error of 0.81 to 1.82 percent is obtained by adding the percents contributed by each error source. The total random error of 1.12 percent is obtained by taking the square root of the sum of the squared percents of the random sources. Taking the square root of the sum of the squares of the random and bias errors gives a total system error of 1.38 to 2.14 percent.

Error Source	Bias Error (percent)	Random Error (percent)
Cross beam angle measurement	±0.81	N/A
Diverging fringes	A	A
Time jitter	N/A	N/A
Clock synchronization	0.51	± 0.51
Quantization	A	± .99
Velocity bias	B	B
Bragg Bias	B	B
Velocity Gradient	B	B
Particle Lag	± 0.50	B
Total error	-0.81 to 1.82	1.12
Total system error	1.38 to 2.14 percent velocity	

A	Not measured
B	Negligible
N/A	Not Applicable

TEST PROCEDURES

In all cases measurements were made at azimuthal increments of 30° from $\psi = 0$, at 1.95 inches (approximately 0.75 chord) above the plane formed by the tips of the blades. Measurements were made from a radial location of r/R = 0.2 to r/R = 1.10, with the majority of the measurement locations concentrated toward the outboard portion of the disk. Figure 8 shows the measurement locations superimposed on the rotor disk. During the test, the rotor tip path plane was maintained at -4° relative to the freestream by zeroing the blade flapping relative to the shaft and setting the shaft angle to -4°. The operating tip speed for the test was held at 624 feet/sec (2113 rpm), the nominal tunnel speed was 188 ft/sec ($\mu = 0.30$), and the nominal rotor thrust coefficient was 0.0065. Table 2 lists the nominal test conditions and selected test parameters. The LV data acquisition process consisted of placing the sample volume at the measurement location and acquiring data for a period of one minute or until 4096 velocity measurements were made in either the longitudinal or the vertical component. During this process, conditional sampling techniques were employed to permanently associate each measured velocity with the location of the rotor blades at the time when the measurement was made. At the conclusion of the process, the measurement location was changed and the acquisition process was repeated.

DATA REDUCTION

Independent velocity measurements in the freestream and vertical direction were made at each measurement location. At the same instant in time that a velocity measurement was made, the location of the blades was recorded for that velocity component. The maximum time required to acquire this data was one minute (2113 rotor revolutions for this test) and the minimum approximately 10 seconds. These data, collected over many revolutions, were sorted into 128 equally spaced azimuth segments (2.81° wide) that are representive of blade position. Careful measurements indicated that the lead-lag motion was well within this azimuth resolution (2.81°); therefore, no corrections to blade position were made due to lead-lag. The velocity value assigned to each interval at a measurement location is the arithmetic mean of all the measurements that were taken in the respective 2.81 degree wide azimuthal range. The results of this sorting process provide the azimuthally dependent velocity data. The "mean velocity" value refers to the velocity calculated from the arithmetic mean of all the measurements made at a single measurement location.

EXPERIMENTAL RESULTS

Table 3 lists the measurement locations, the mean and standard deviation of the two components of induced inflow ratio, and the number of measurements in each of the measured components (U and V). In figure 9 the mean longitudinal induced component of velocity, μ_i, with a band of ± one standard deviation is plotted vs. blade radius for each radial scan. The standard deviation represents the fluctuation in velocity at a given measurement location; it is not an indication of the error in the mean measurements. The size of the symbols used for plotting the mean velocity values is an approximation of the calculated error in the measurements. Figure 10 presents in the same format the mean normal induced component of velocity, λ_i. The same data without the ± one standard deviation is presented in a contour plot format in figures 11 and 12 in order to show more clearly the interactions over the whole disk (viewed from above). Azimuth dependent data are presented in figures 13-192. The format of each of these figures shows the induced velocity vs azimuth at the top of the figure, the number of measurements that were used to determine the induced inflow velocity ratio for each azimuth segment in the center, and an order ratio analysis of the azimuthal variation at the bottom of the figure. The figure numbers for the azimuthal and radial measurement locations follow:

Azimuth	0	30	60	90	120	150	180	210	240	270	300	330
r/R												
0.20	13	28	43	58	73	88	103	118	133	148	163	178
0.40	14	29	44	59	74	89	104	119	134	149	164	179
0.50	15	30	45	60	75	90	105	120	135	150	165	180
0.60	16	31	46	61	76	91	106	121	136	151	166	181
0.70	17	32	47	62	77	92	107	122	137	152	167	182
0.74	18	33	48	63	78	93	108	123	138	153	168	183
0.78	19	34	49	64	79	94	109	124	139	154	169	184
0.82	20	35	50	65	80	95	110	125	140	155	170	185
0.86	21	36	51	66	81	96	111	126	141	156	171	186
0.90	22	37	52	67	82	97	112	127	142	157	172	187
0.94	23	38	53	68	83	98	113	128	143	158	173	188
0.98	24	39	54	69	84	99	114	129	144	159	174	189
1.02	25	40	55	70	85	100	115	130	145	160	175	190
1.04	26	41	56	71	86	101	116	131	146	161	176	191
1.10	27	42	57	72	87	102	117	132	147	162	177	192

The mean and standard deviation of the induced inflow velocities (table 3) and the azimuthally dependent induced inflow velocities (figures 13 through 192) are included on a 5.25 flexible disk in the pocket on the inside of the rear cover of this report. The details of the data format and the file structure are located in the file "README.DOC". The disk format is 360 kbyte double-sided, written using the Micrsoft Corporation MS-DOS operating system.

CONCLUDING REMARKS

The laser velocimeter provides an effective system for making measurements in the dynamic environment associated with rotor blades. It has been used on numerous occasions to measure the localized flow phenomena encountered in such flows. This investigation demonstrates the use of a matured LV system to map the flow into a representative rotor in forward flight by making velocity measurements at 180 locations above the rotor disk. These measurements provide both the mean and azimuthally-dependent velocity values, and they provide a detailed look at the nature of this flow. The mean and standard deviation of the induced inflow velocities and the azimuthally dependent induced inflow velocities are included on a 5.25 flexible disk in the pocket on the inside of the rear cover of this report.

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TABLE 1 - 2MRTS ROTOR AND BLADE CHARACTERSTICS

Hub Type	Fully Articulated
Number of blades	4
Airfoil section	NACA 0012
Hinge offset, in, r/R	2.00, .06
Root cutout, in, r/R	8.25, .24
Pitch-flap coupling angle, deg	0.0
Twist linear, deg	-8.0
Radius, R, in	33.88
Airfoil chord, C, in	2.6
Rotor solidity, $bc/\pi R$	0.0977
Blade stiffness	
Flapwise lb-in^2	11500
Torsional lb-in^2	25500
Blade weight, grams	259.3
Lead/lag damping' in-lb/deg/sec	182.4

TABLE 2 - NOMINAL ROTOR CONTROL AND PERFORMANCE PARAMETERS

C_T	0.00646
C_Q	0.00037
C_D	0.0002
α, deg	-4.02
Coning, deg	1.0
A_0, deg	7.1
A_1, deg	-1.8
B_1, deg	5.3
μ_∞	0.301
V_∞, ft/sec	188.2
V_{tip}, ft/sec	624.8
Lag angle (mean), degrees	1.0

TABLE 3 - INFLOW VELOCITY SUMMARY

		μ_i			λ_i		
Ψ	r/R	Mean	Standard deviation	# of Measurements	Mean	Standard deviation	# of Measurements
0	0.20	0.0105	0.0172	1310	-0.0077	0.0186	2938
0	0.40	0.0121	0.0151	2329	-0.0178	0.0133	2929
0	0.50	0.0133	0.0123	2485	-0.0217	0.0121	2839
0	0.60	0.0127	0.0115	2527	-0.0244	0.0117	2871
0	0.70	0.0120	0.0098	2596	-0.0272	0.0095	2925
0	0.74	0.0114	0.0094	2541	-0.0288	0.0086	2874
0	0.78	0.0107	0.0095	2601	-0.0297	0.0086	2923
0	0.82	0.0094	0.0094	2613	-0.0308	0.0085	2914
0	0.86	0.0079	0.0091	2692	-0.0322	0.0084	2917
0	0.90	0.0064	0.0090	2647	-0.0325	0.0083	2933
0	0.94	0.0050	0.0090	2674	-0.0334	0.0080	2918
0	0.98	0.0046	0.0089	2752	-0.0338	0.0075	2933
0	1.02	0.0012	0.0094	2721	-0.0339	0.0067	2932
0	1.04	0.0007	0.0094	2779	-0.0340	0.0060	3014
0	1.10	-0.0008	0.0093	2698	-0.0334	0.0053	2947
30	0.20	0.0147	0.0150	1437	0.0091	0.0142	2946
30	0.40	0.0124	0.0111	2530	-0.0148	0.0089	2911
30	0.50	0.0105	0.0093	2719	-0.0238	0.0074	3090
30	0.60	0.0092	0.0093	2657	-0.0280	0.0067	3062
30	0.70	0.0064	0.0088	2662	-0.0300	0.0071	3054
30	0.74	0.0085	0.0084	2750	-0.0306	0.0070	3023
30	0.78	0.0073	0.0076	2651	-0.0309	0.0072	3038
30	0.82	0.0057	0.0085	2691	-0.0312	0.0072	3052
30	0.86	0.0053	0.0088	2729	-0.0319	0.0070	3047
30	0.90	0.0025	0.0087	2753	-0.0316	0.0070	3089
30	0.94	0.0020	0.0085	2677	-0.0311	0.0063	3089
30	0.98	0.0004	0.0082	2785	-0.0300	0.0054	3086
30	1.02	-0.0013	0.0082	2766	-0.0286	0.0046	3045
30	1.04	-0.0016	0.0084	2703	-0.0278	0.0042	3025
30	1.10	-0.0038	0.0081	2725	-0.0254	0.0035	2999
60	0.20	0.0091	0.0105	2466	0.0001	0.0115	3072
60	0.40	0.0100	0.0085	2577	-0.0210	0.0080	3217
60	0.50	0.0092	0.0087	2648	-0.0196	0.0083	3194
60	0.60	0.0078	0.0098	2168	-0.0186	0.0060	3260
60	0.70	-0.0060	0.0083	1504	0.0182	0.0045	3154
60	0.74	-0.0067	0.0082	1538	0.0173	0.0035	3108
60	0.78	-0.0018	0.0107	2672	0.0166	0.0032	3161
60	0.82	-0.0013	0.0112	2751	0.0165	0.0034	3123
60	0.86	-0.0006	0.0112	2725	0.0163	0.0034	3167
60	0.90	-0.0012	0.0115	2735	0.0161	0.0030	3175
60	0.94	-0.0013	0.0113	2728	0.0158	0.0032	3129
60	0.98	-0.0025	0.0115	2696	0.0158	0.0031	3112
60	1.02	-0.0021	0.0103	2599	0.0156	0.0030	3059
60	1.04	-0.0020	0.0102	2661	0.0155	0.0031	3076
60	1.10	-0.0022	0.0102	2571	0.0152	0.0030	3011

TABLE 3 - CONTINUED

		μ_i			λ_i		
Ψ	r/R	Mean	Standard deviation	# of Measurements	Mean	Standard deviation	# of Measurements
90	0.20	0.0069	0.0110	2253	-0.0005	0.0069	2807
90	0.40	0.0146	0.0151	2455	-0.0140	0.0089	2936
90	0.50	0.0114	0.0151	2441	-0.0109	0.0095	2940
90	0.60	0.0081	0.0144	2408	-0.0055	0.0095	2931
90	0.70	-0.0032	0.0114	2458	0.0110	0.0046	2892
90	0.74	-0.0043	0.0112	2389	0.0111	0.0044	2874
90	0.78	-0.0047	0.0116	2469	0.0109	0.0042	2839
90	0.82	-0.0037	0.0112	2424	0.0105	0.0045	2857
90	0.86	-0.0032	0.0109	2427	0.0102	0.0043	2918
90	0.90	-0.0021	0.0117	2447	0.0102	0.0043	2897
90	0.94	-0.0028	0.0116	2443	0.0101	0.0040	2877
90	0.98	-0.0033	0.0108	2480	0.0101	0.0041	2899
90	1.02	-0.0039	0.0107	2472	0.0098	0.0040	2908
90	1.04	-0.0043	0.0108	2463	0.0098	0.0040	2894
90	1.10	-0.0041	0.0108	2457	0.0094	0.0042	2929
120	0.20	0.0022	0.0107	2226	0.0012	0.0074	2722
120	0.40	0.0102	0.0118	2385	-0.0066	0.0085	2925
120	0.50	0.0111	0.0113	2946	-0.0038	0.0123	3299
120	0.60	0.0077	0.0113	2902	0.0017	0.0135	3388
120	0.70	-0.0055	0.0089	2952	0.0086	0.0036	3462
120	0.74	-0.0055	0.0092	2956	0.0083	0.0037	3475
120	0.78	-0.0051	0.0091	2951	0.0077	0.0036	3539
120	0.82	-0.0049	0.0087	2900	0.0075	0.0034	3512
120	0.86	-0.0058	0.0085	2928	0.0073	0.0035	3529
120	0.90	-0.0050	0.0079	2853	0.0066	0.0034	3560
120	0.94	-0.0056	0.0085	2929	0.0066	0.0035	3580
120	0.98	-0.0052	0.0088	2876	0.0061	0.0034	3594
120	1.02	-0.0052	0.0089	2823	0.0061	0.0033	3525
120	1.04	-0.0042	0.0093	2909	0.0059	0.0029	3490
120	1.10	-0.0032	0.0155	3096	0.0054	0.0028	3597
150	0.20	0.0026	0.0126	2596	0.0047	0.0088	3065
150	0.40	0.0074	0.0114	2737	-0.0034	0.0130	3317
150	0.50	0.0074	0.0116	2653	0.0000	0.0132	3281
150	0.60	0.0069	0.0120	2564	0.0044	0.0108	3248
150	0.70	0.0047	0.0111	2687	0.0068	0.0142	3286
150	0.74	0.0040	0.0116	2758	0.0081	0.0143	3353
150	0.78	0.0029	0.0119	2697	0.0093	0.0139	3257
150	0.82	0.0006	0.0120	2718	0.0105	0.0135	3331
150	0.86	-0.0014	0.0115	2619	0.0107	0.0125	3258
150	0.90	-0.0018	0.0126	2597	0.0107	0.0107	3222
150	0.94	-0.0041	0.0109	2628	0.0120	0.0077	3232
150	0.98	-0.0046	0.0109	2735	0.0118	0.0066	3377
150	1.02	-0.0053	0.0104	2596	0.0102	0.0043	3227
150	1.04	-0.0074	0.0092	2730	0.0096	0.0043	3301
150	1.10	-0.0033	0.0190	2989	0.0077	0.0039	3152

TABLE 3 - CONTINUED

		μ_i			λ_i		
ψ	r/R	Mean	Standard deviation	# of Measurements	Mean	Standard deviation	# of Measurements
180	0.20	-0.0016	0.0128	2424	0.0074	0.0121	3169
180	0.40	0.0063	0.0111	2571	0.0038	0.0130	3181
180	0.50	0.0079	0.0115	2683	0.0066	0.0106	3195
180	0.60	0.0073	0.0126	2828	0.0099	0.0148	2988
180	0.70	0.0022	0.0113	2782	0.0120	0.0169	3184
180	0.74	0.0010	0.0116	2828	0.0136	0.0173	3350
180	0.78	-0.0001	0.0122	2838	0.0121	0.0161	3236
180	0.82	-0.0021	0.0103	2812	0.0120	0.0139	3149
180	0.86	-0.0017	0.0114	2865	0.0124	0.0144	3248
180	0.90	-0.0039	0.0110	2865	0.0128	0.0127	3239
180	0.94	-0.0056	0.0103	2865	0.0130	0.0102	3210
180	0.98	-0.0070	0.0092	2874	0.0129	0.0071	3199
180	1.02	-0.0076	0.0082	2862	0.0113	0.0051	3190
180	1.04	-0.0082	0.0084	2852	0.0104	0.0050	3138
180	1.10	-0.0076	0.0082	2879	0.0082	0.0042	3131
210	0.20	-0.0050	0.0102	2670	0.0094	0.0088	3060
210	0.40	0.0029	0.0097	2642	0.0022	0.0093	3167
210	0.50	0.0076	0.0140	2655	0.0035	0.0118	3071
210	0.60	0.0050	0.0145	2687	0.0036	0.0173	3073
210	0.70	0.0031	0.0145	2690	0.0041	0.0166	3024
210	0.74	0.0025	0.0143	2741	0.0042	0.0168	3077
210	0.78	0.0029	0.0145	2712	0.0051	0.0163	3069
210	0.82	0.0027	0.0146	2824	0.0064	0.0158	3118
210	0.86	-0.0001	0.0131	2732	0.0080	0.0143	3109
210	0.90	-0.0010	0.0125	2708	0.0087	0.0131	3051
210	0.94	-0.0020	0.0119	2720	0.0098	0.0101	3080
210	0.98	-0.0042	0.0094	2718	0.0103	0.0066	3033
210	1.02	-0.0053	0.0083	2727	0.0095	0.0052	3021
210	1.04	-0.0053	0.0082	2659	0.0087	0.0047	2989
210	1.10	-0.0066	0.0083	2743	0.0070	0.0042	3021
240	0.20	-0.0030	0.0097	2668	0.0085	0.0073	3057
240	0.40	0.0040	0.0116	2127	-0.0012	0.0062	3084
240	0.50	0.0014	0.0123	2790	-0.0003	0.0088	3060
240	0.60	0.0006	0.0153	2754	0.0004	0.0145	3096
240	0.70	0.0011	0.0146	2864	-0.0009	0.0162	3085
240	0.74	0.0014	0.0141	2739	-0.0005	0.0163	2991
240	0.78	0.0012	0.0147	2746	0.0009	0.0164	3038
240	0.82	0.0016	0.0145	2736	0.0015	0.0164	3019
240	0.86	0.0008	0.0132	2677	0.0040	0.0149	2949
240	0.90	0.0009	0.0128	2734	0.0056	0.0138	2988
240	0.94	0.0007	0.0113	2652	0.0072	0.0122	3030
240	0.98	0.0014	0.0091	2627	0.0091	0.0082	2924
240	1.02	0.0003	0.0083	2536	0.0096	0.0061	2857
240	1.04	0.0002	0.0081	2547	0.0092	0.0051	2856
240	1.10	-0.0003	0.0081	2570	0.0077	0.0046	2849

TABLE 3 - CONCLUDED

		μ_i			λ_i		
Ψ	r/R	Mean	Standard deviation	# of Measurements	Mean	Standard deviation	# of Measurements
270	0.20	0.0018	0.0091	2814	-0.0030	0.0057	3014
270	0.40	0.0010	0.0089	2802	-0.0119	0.0052	3042
270	0.50	0.0006	0.0081	2923	-0.0142	0.0051	2952
270	0.60	-0.0004	0.0086	2836	-0.0158	0.0056	2989
270	0.70	0.0030	0.0096	2946	-0.0171	0.0074	2982
270	0.74	0.0043	0.0108	2855	-0.0170	0.0083	2967
270	0.78	0.0043	0.0114	2872	-0.0176	0.0096	3002
270	0.82	0.0040	0.0116	2922	-0.0167	0.0108	2983
270	0.86	0.0052	0.0113	2880	-0.0152	0.0125	3034
270	0.90	0.0083	0.0118	2569	-0.0136	0.0131	2956
270	0.94	0.0062	0.0100	2658	-0.0097	0.0119	2868
270	0.98	0.0070	0.0097	2277	-0.0050	0.0090	2802
270	1.02	0.0046	0.0096	2221	0.0000	0.0056	2604
270	1.04	0.0018	0.0100	2250	0.0013	0.0048	2589
270	1.10	-0.0005	0.0096	2356	0.0007	0.0046	2682
300	0.20	0.0074	0.0098	2500	0.0069	0.0068	2835
300	0.40	0.0046	0.0100	2254	0.0010	0.0055	2708
300	0.50	0.0024	0.0092	2538	-0.0018	0.0053	2829
300	0.60	0.0024	0.0093	2613	-0.0041	0.0057	2894
300	0.70	0.0001	0.0099	2785	-0.0065	0.0066	3026
300	0.74	0.0026	0.0098	2754	-0.0090	0.0082	2876
300	0.78	0.0031	0.0109	2875	-0.0091	0.0062	2946
300	0.82	0.0035	0.0108	2885	-0.0101	0.0062	3010
300	0.86	0.0044	0.0110	2817	-0.0119	0.0066	2974
300	0.90	0.0040	0.0110	2782	-0.0135	0.0072	2892
300	0.94	0.0046	0.0127	2536	-0.0151	0.0074	2952
300	0.98	0.0027	0.0118	2584	-0.0153	0.0069	2849
300	1.02	0.0033	0.0126	2438	-0.0138	0.0060	2801
300	1.04	0.0043	0.0112	2368	-0.0115	0.0055	2774
300	1.10	0.0069	0.0117	2196	-0.0006	0.0057	2522
330	0.20	0.0113	0.0130	2263	0.0087	0.0124	2800
330	0.40	0.0093	0.0135	2177	0.0034	0.0054	2558
330	0.50	0.0114	0.0123	2296	0.0003	0.0056	2632
330	0.60	0.0072	0.0119	2399	-0.0015	0.0054	2644
330	0.70	0.0088	0.0115	2321	-0.0041	0.0061	2642
330	0.74	0.0089	0.0115	2280	-0.0056	0.0062	2617
330	0.78	0.0101	0.0115	2295	-0.0068	0.0065	2605
330	0.82	0.0087	0.0108	2280	-0.0086	0.0076	2665
330	0.86	0.0077	0.0106	2347	-0.0104	0.0076	2607
330	0.90	0.0084	0.0108	2299	-0.0123	0.0080	2626
330	0.94	0.0074	0.0113	2307	-0.0147	0.0082	2655
330	0.98	0.0063	0.0107	2285	-0.0163	0.0079	2686
330	1.02	0.0054	0.0112	2261	-0.0173	0.0071	2645
330	1.04	0.0052	0.0115	2248	-0.0180	0.0067	2678
330	1.10	0.0025	0.0112	2264	-0.0177	0.0060	2694

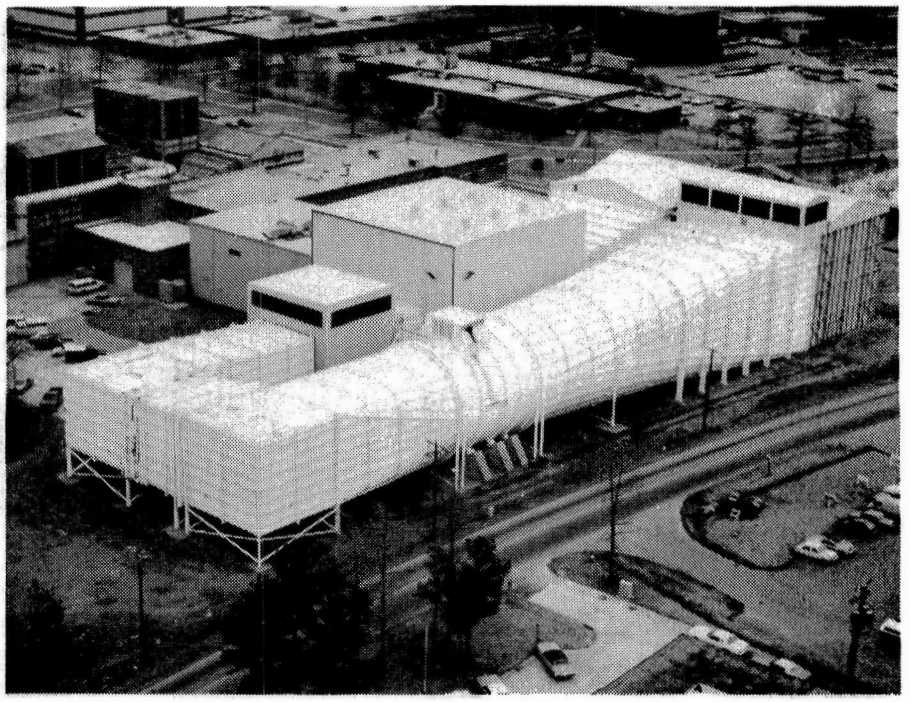


Figure 1. Aerial view of 14- by 22-Foot Subsonic Tunnel.

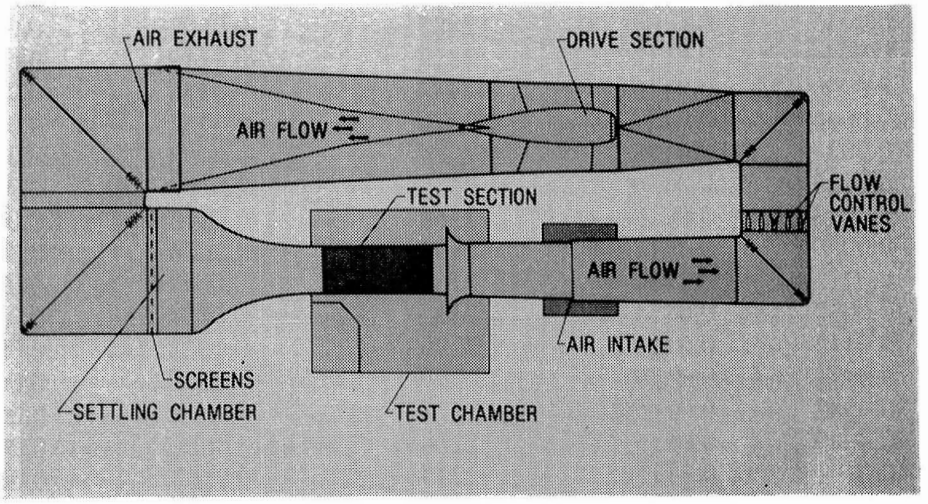


Figure 2. Schematic of 14- by 22-Foot Subsonic Tunnel.

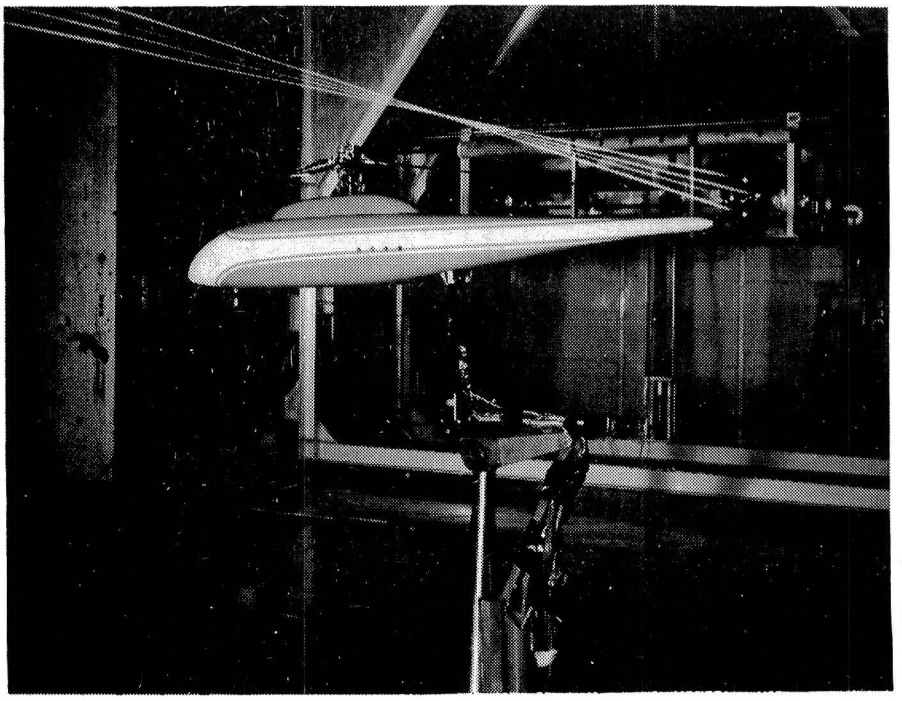


Figure 3. 2MRTS mounted in forward bay of the test section.

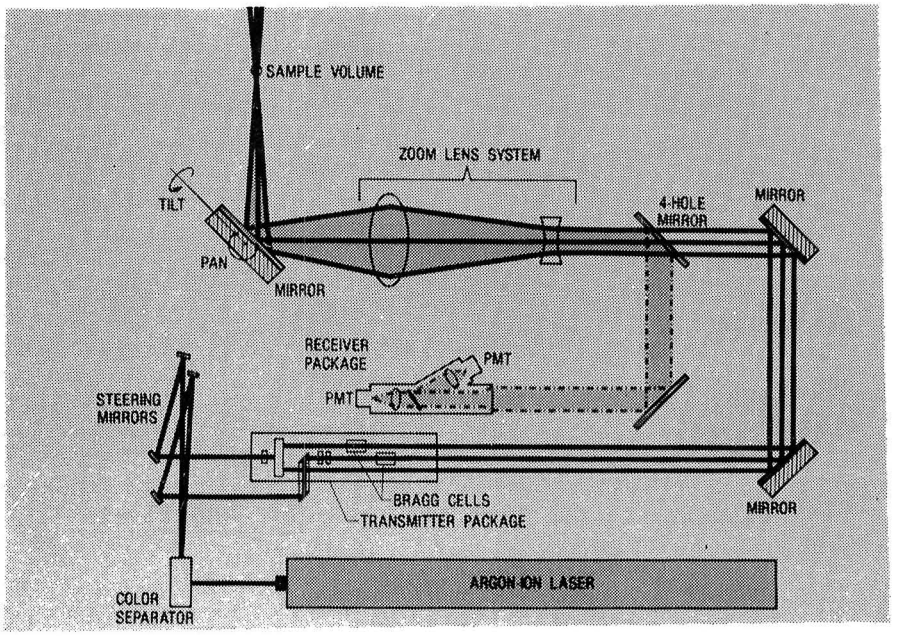


Figure 4. Schematic of laser velocimeter optics subsystem.

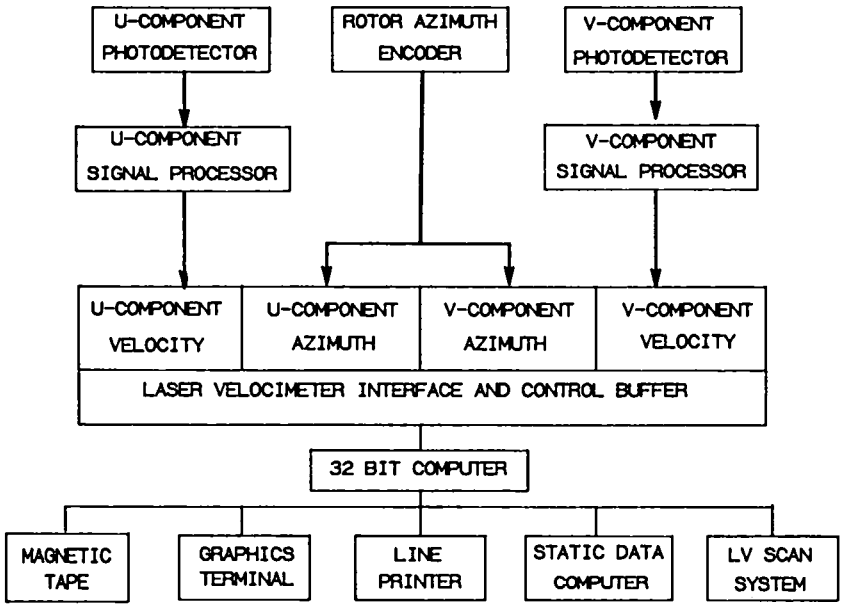


Figure 5. Schematic of data acquisition subsystem.

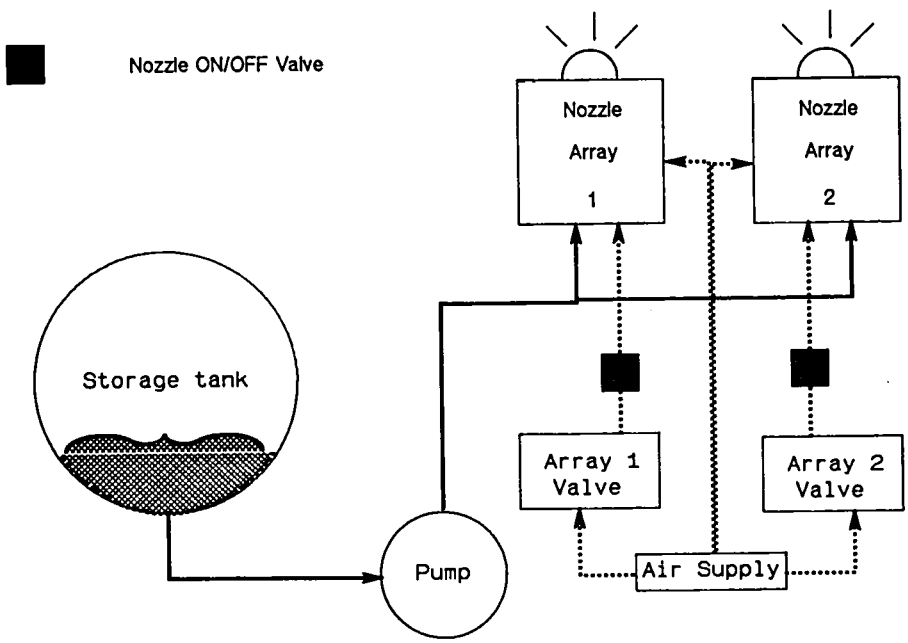


Figure 6. Schematic of seeding subsystem.

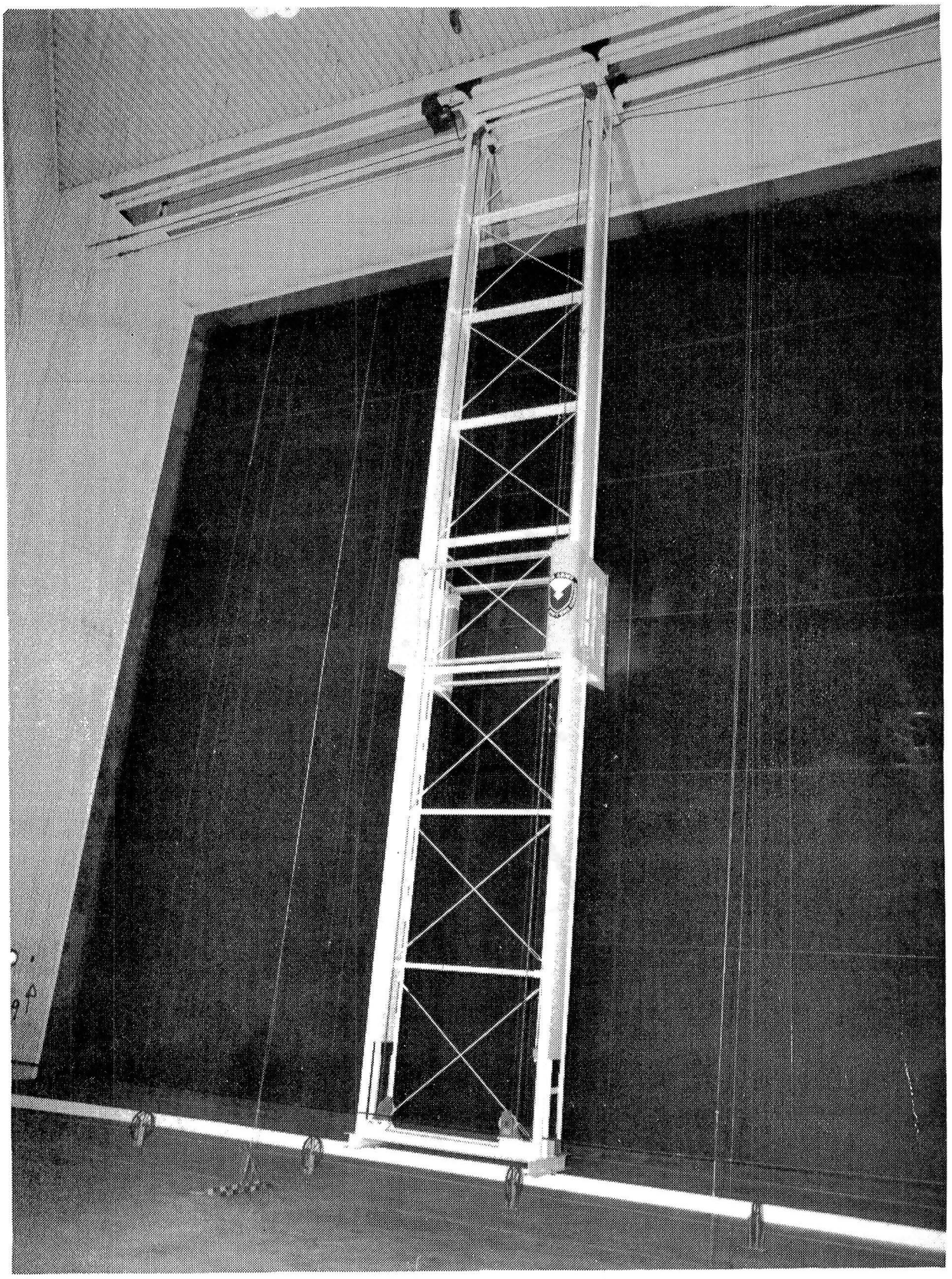


Figure 7. Photograph of remote control positioner for seeding system.

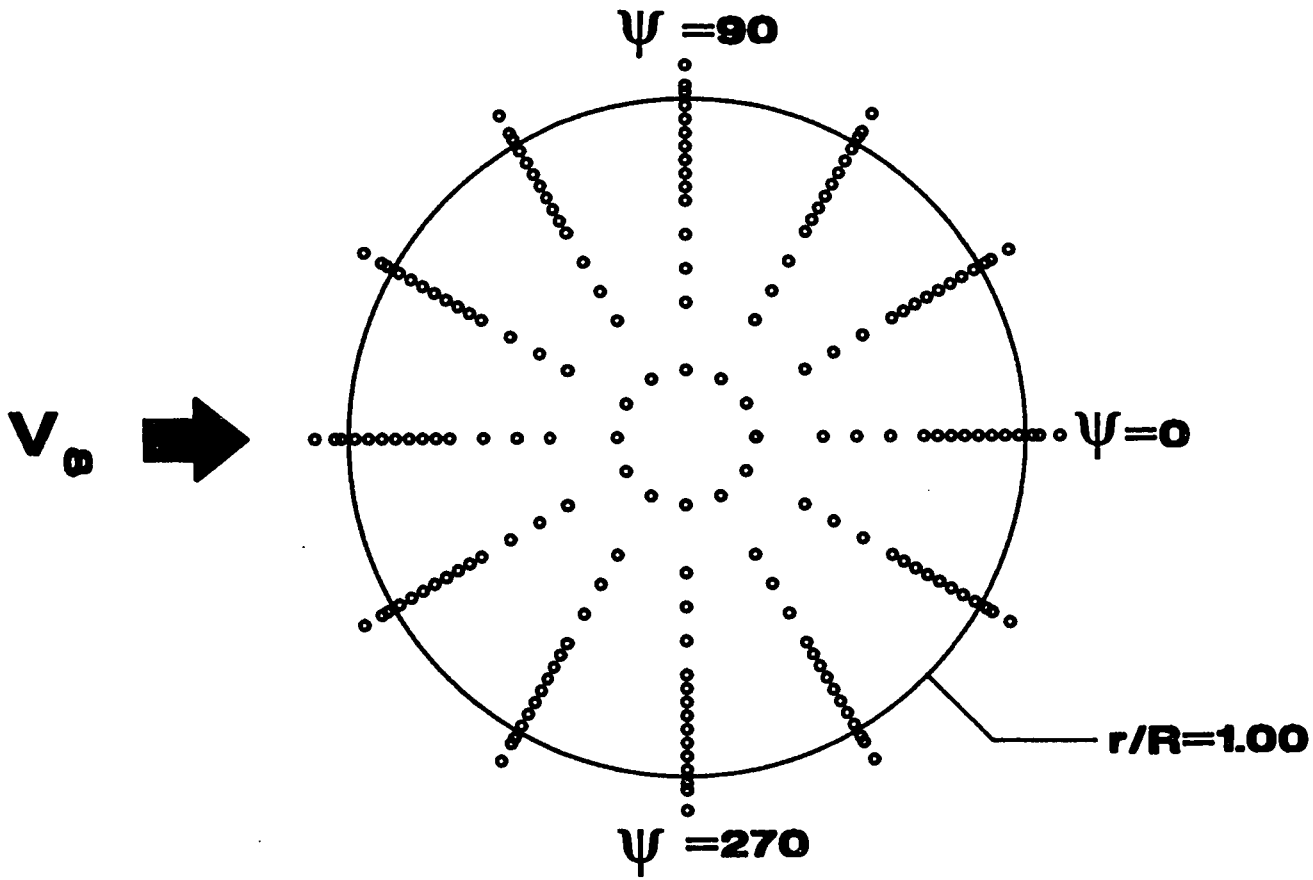
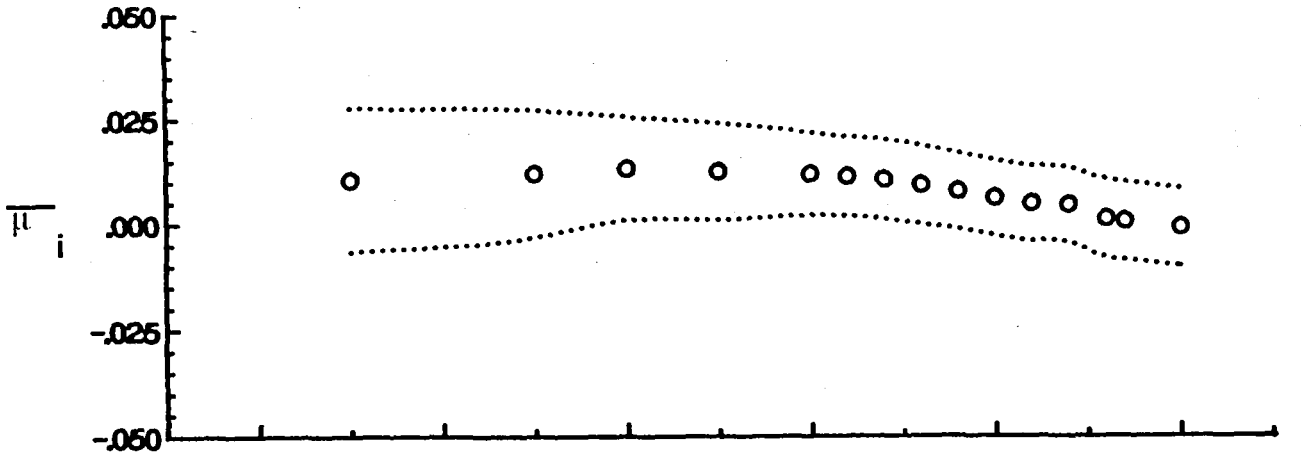
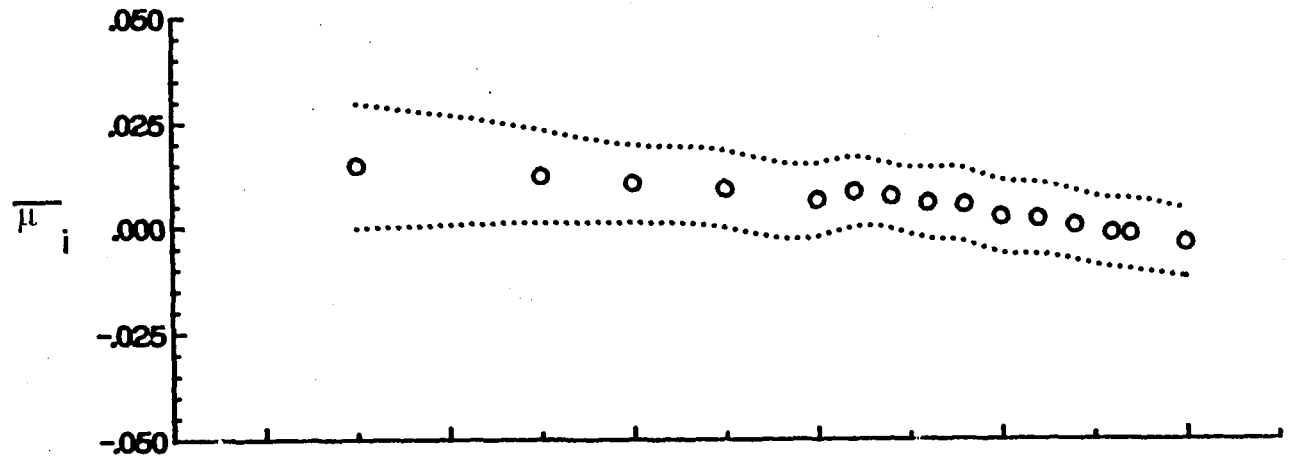


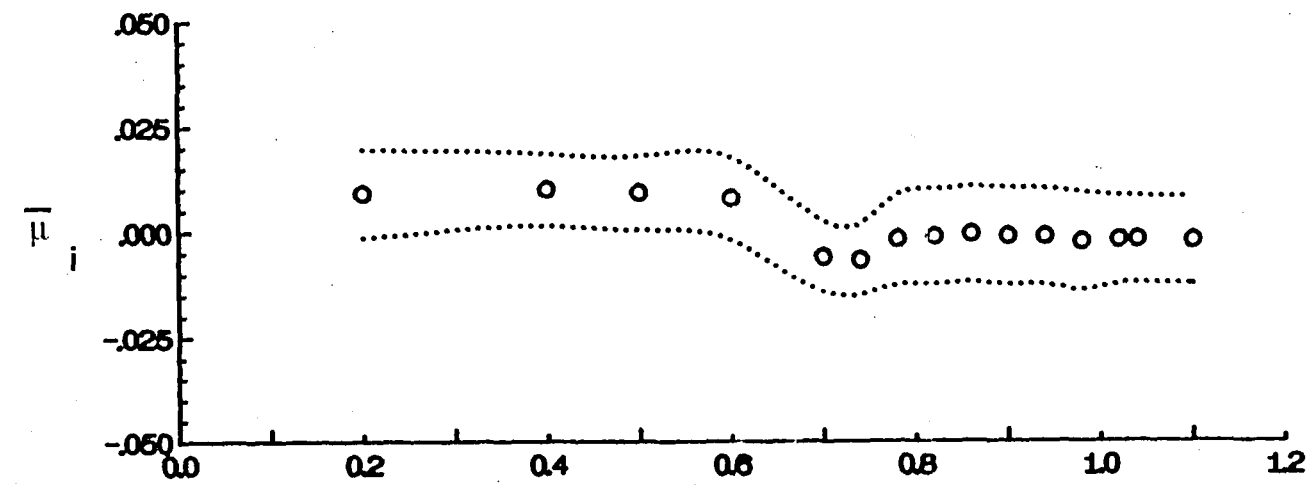
Figure 8. Locations of velocity measurements, 1.95 inches above rotor tip path plane.



(a) rotor azimuth = 0 degrees

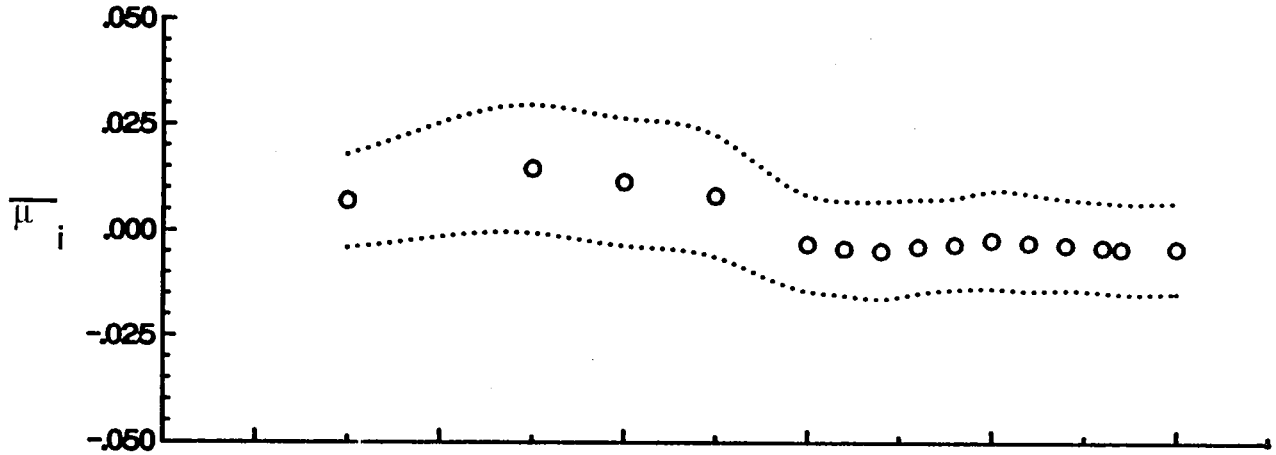


(b) rotor azimuth = 30 degrees

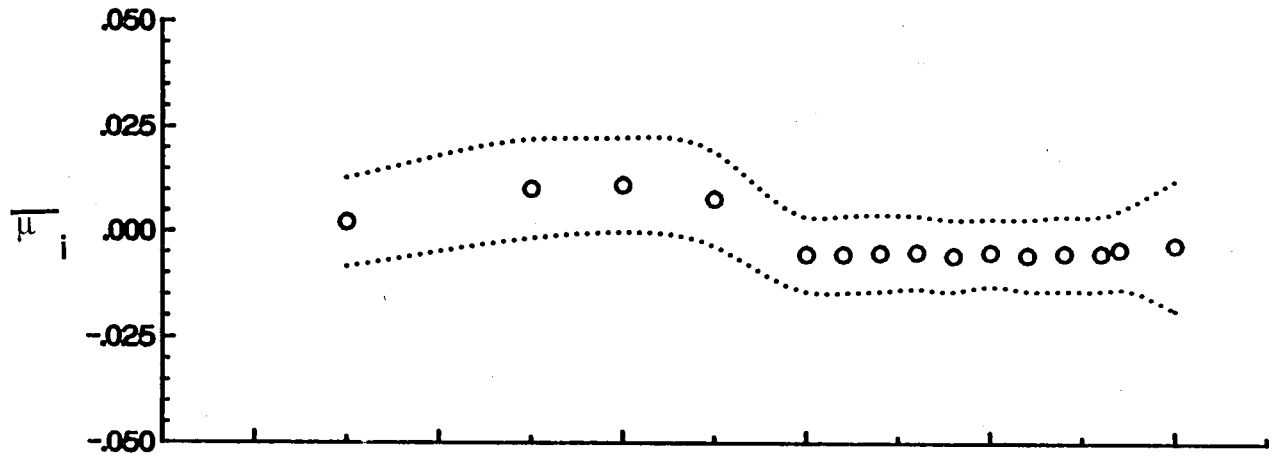


(c) rotor azimuth = 60 degrees

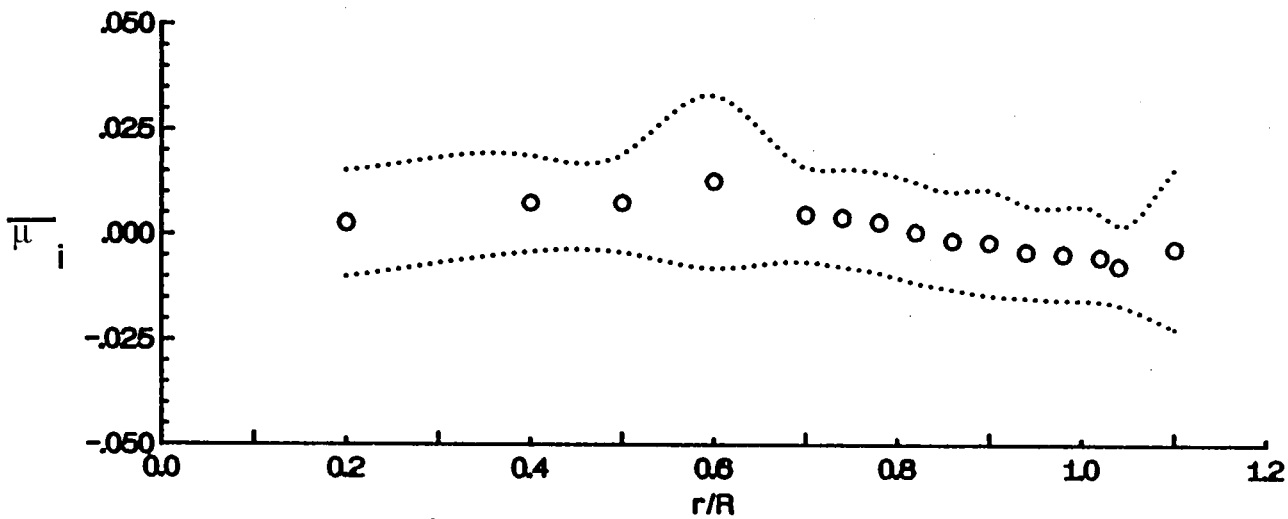
Figure 9.- Radial distribution of mean induced inflow ratio ($\overline{\mu}_i$).



(d) rotor azimuth = 90 degrees

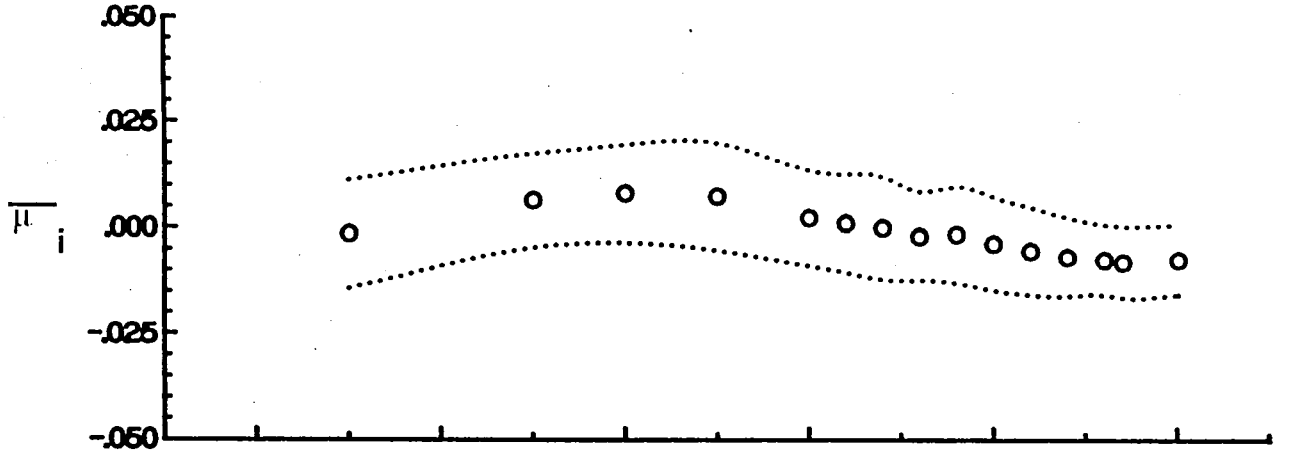


(e) rotor azimuth = 120 degrees

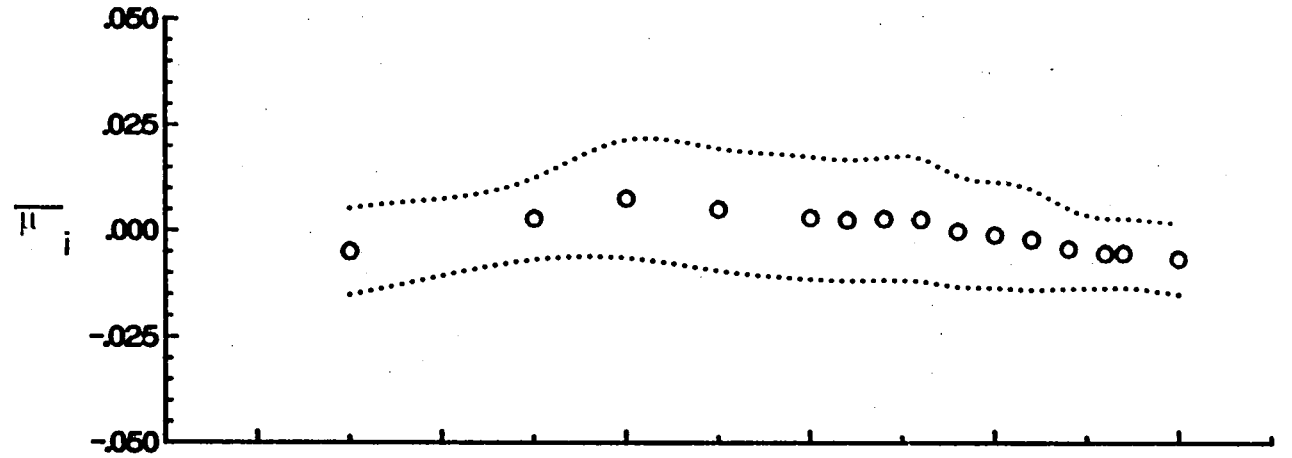


(f) rotor azimuth = 150 degrees

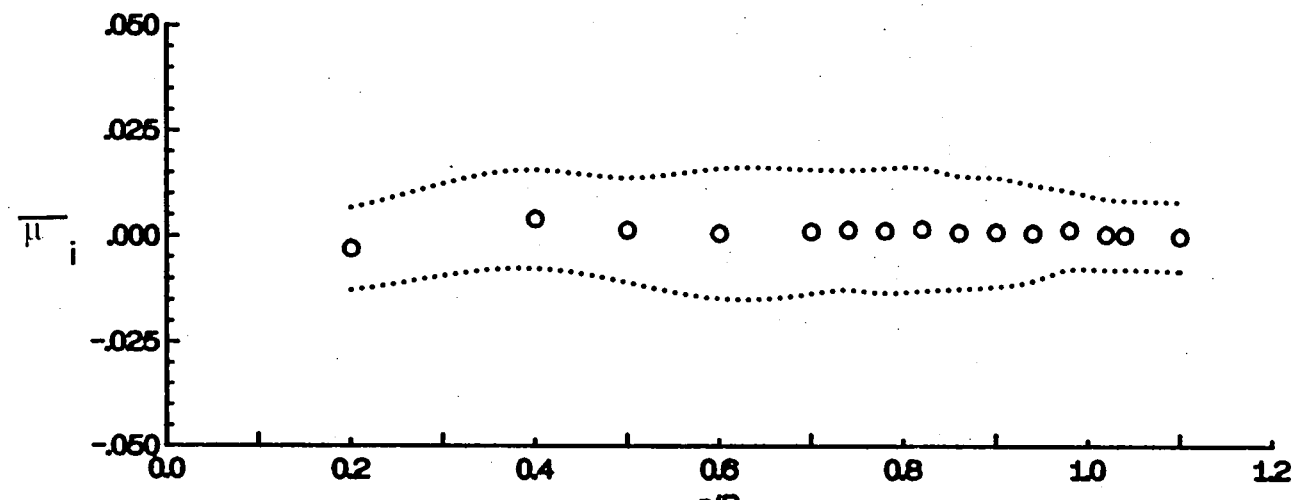
Figure 9.- Continued.



(g) rotor azimuth = 180 degrees

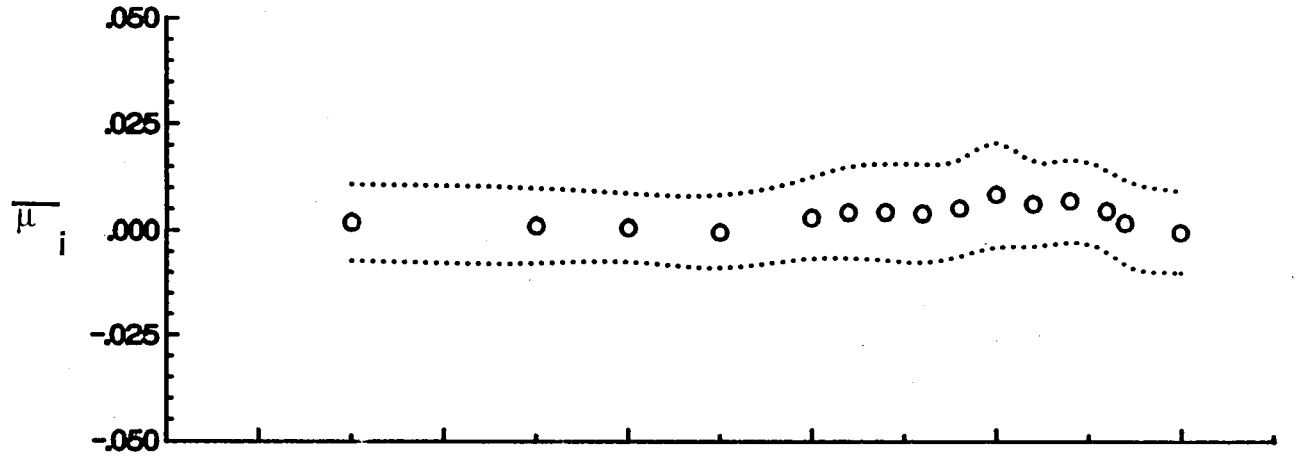


(h) rotor azimuth = 210 degrees

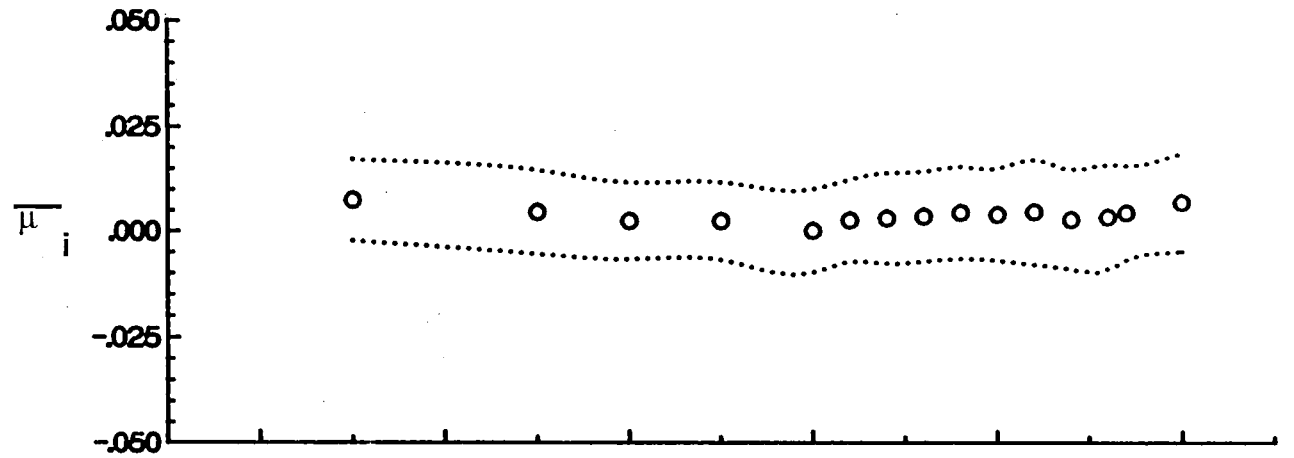


(i) rotor azimuth = 240 degrees

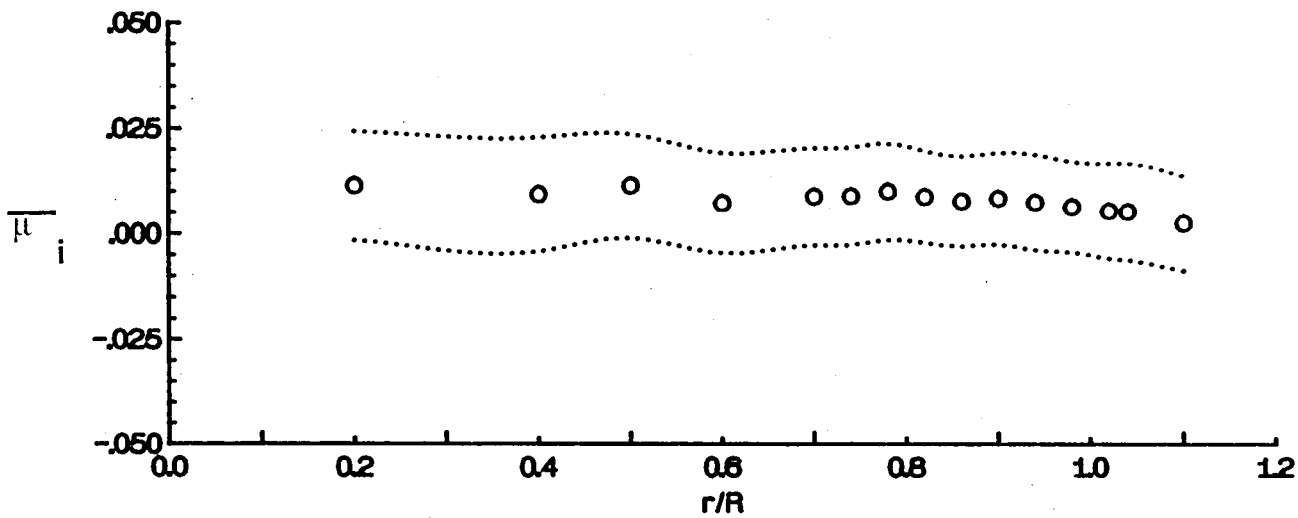
Figure 9.- Continued.



(j) rotor azimuth = 270 degrees



(k) rotor azimuth = 300 degrees



(l) rotor azimuth = 330 degrees

Figure 9.- Concluded.

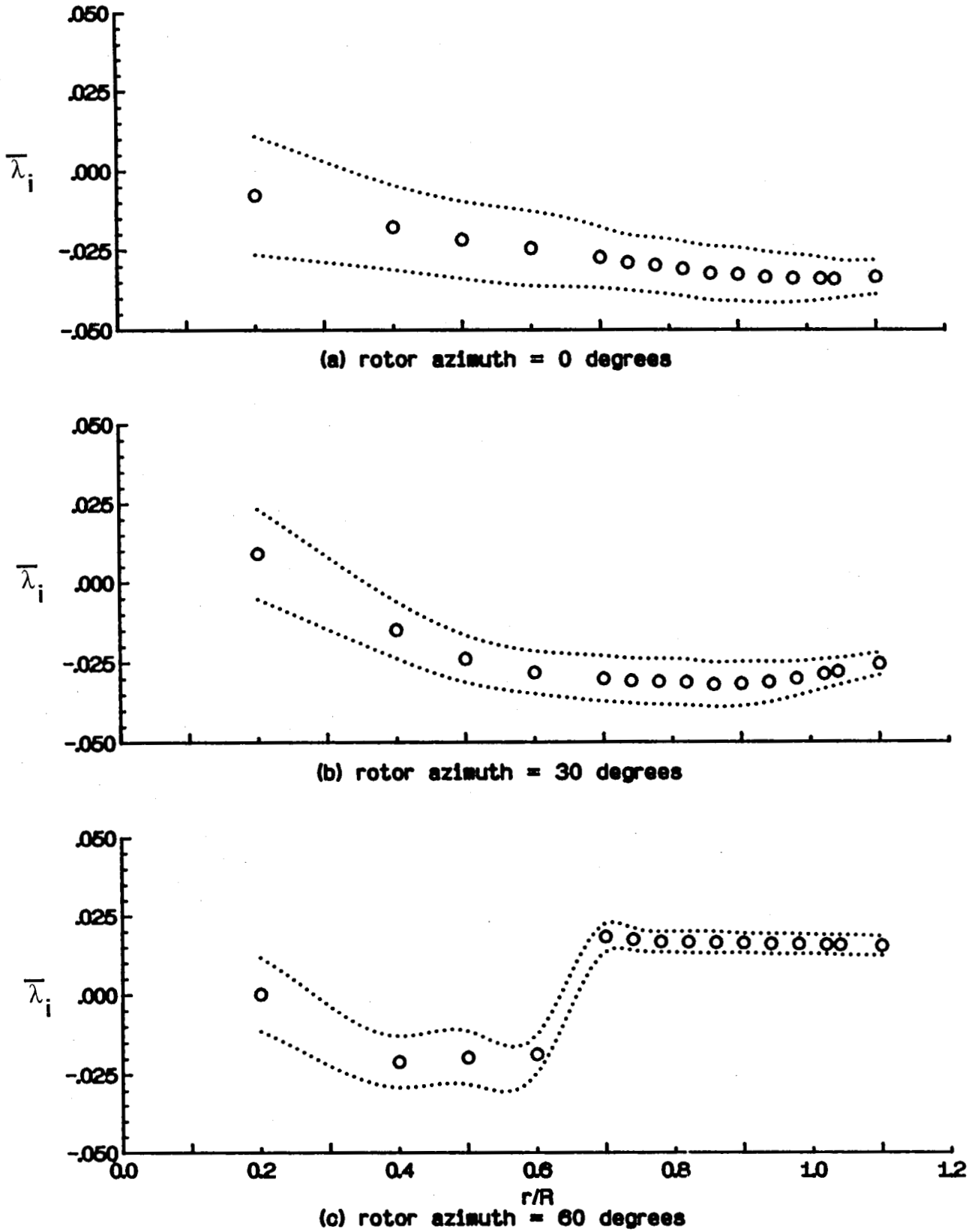
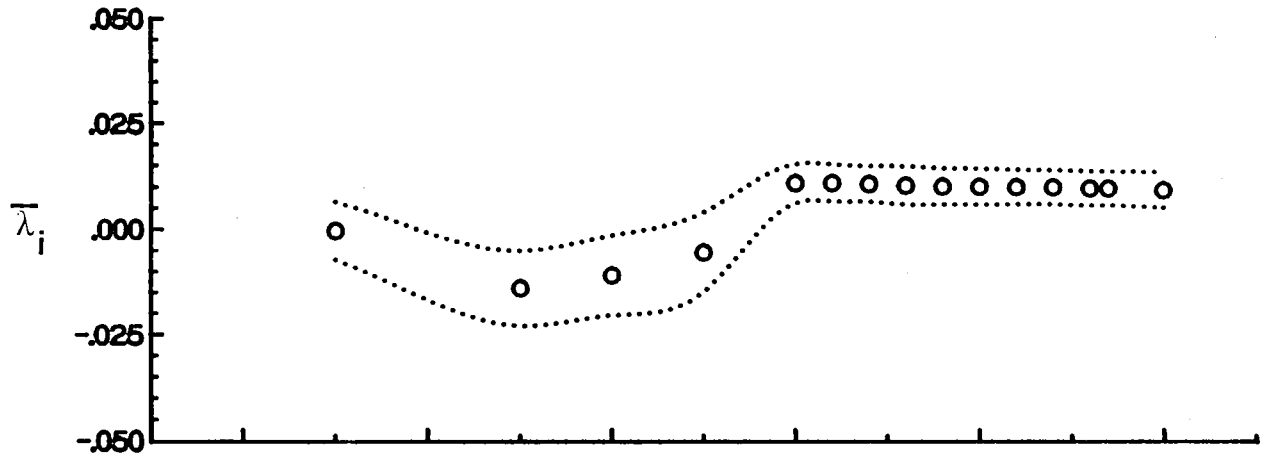
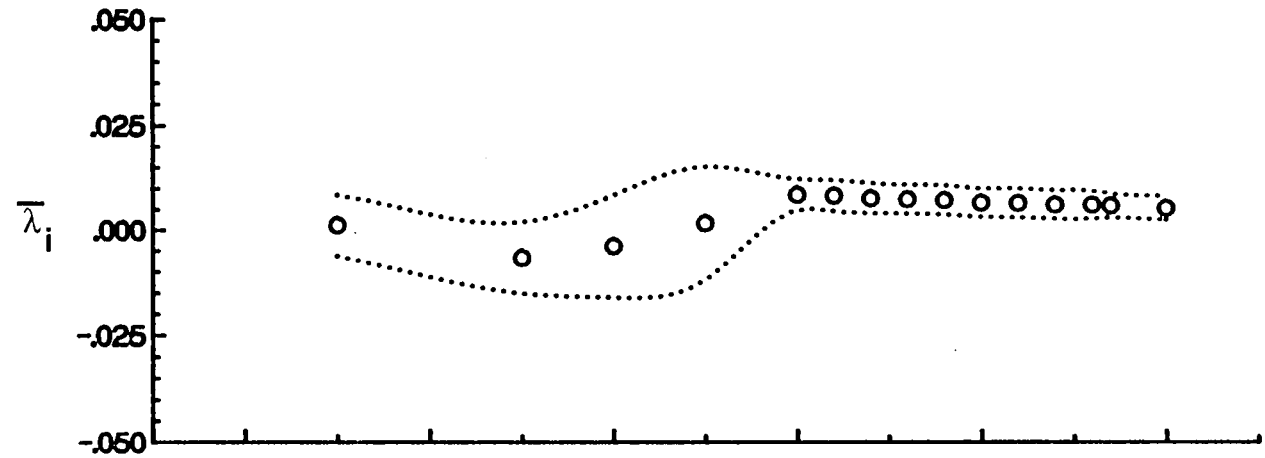


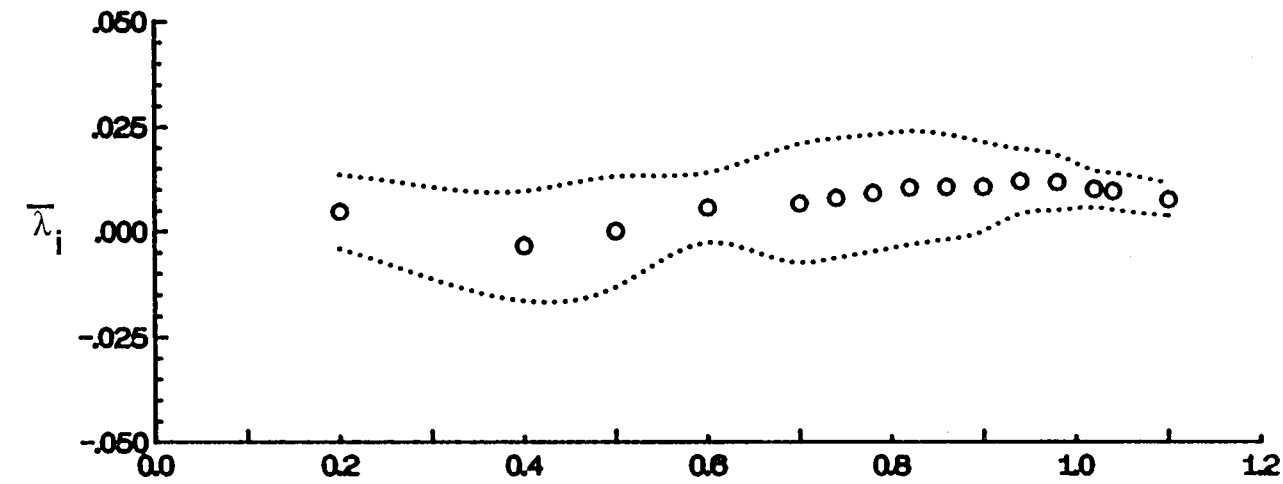
Figure 10.- Radial distribution of mean induced inflow ratio ($\overline{\lambda}_i$).



(d) rotor azimuth = 90 degrees

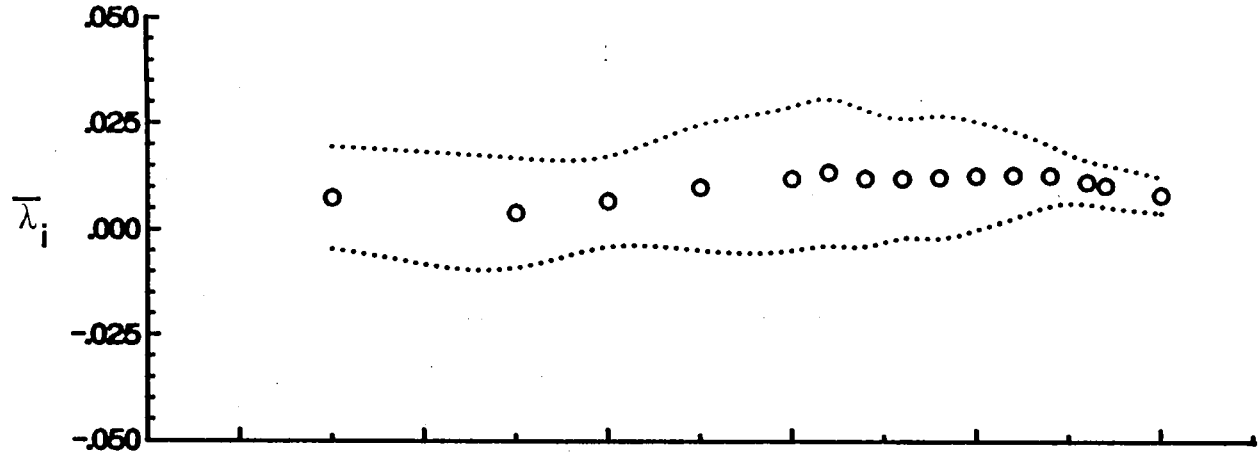


(e) rotor azimuth = 120 degrees

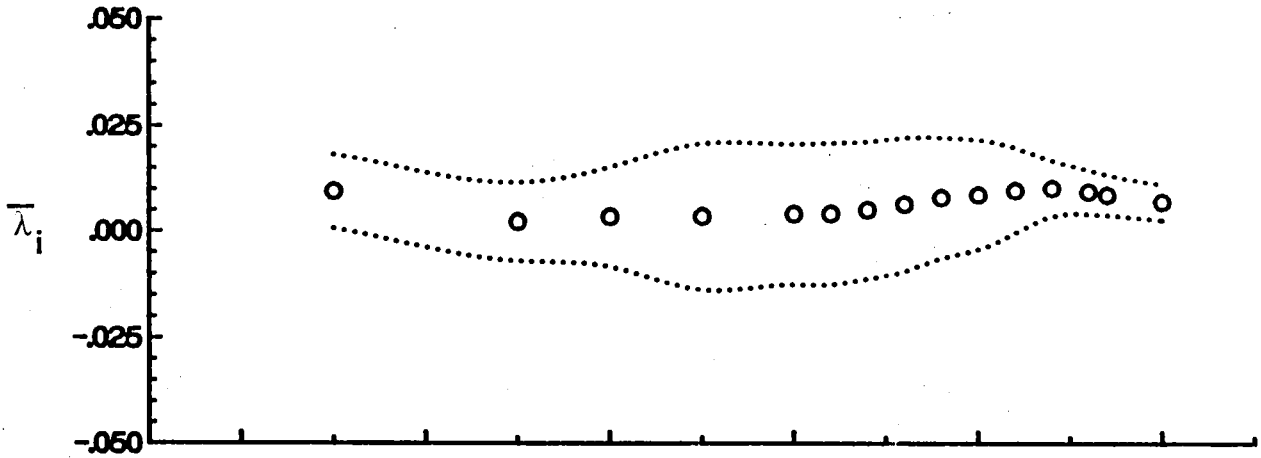


(f) rotor azimuth = 150 degrees

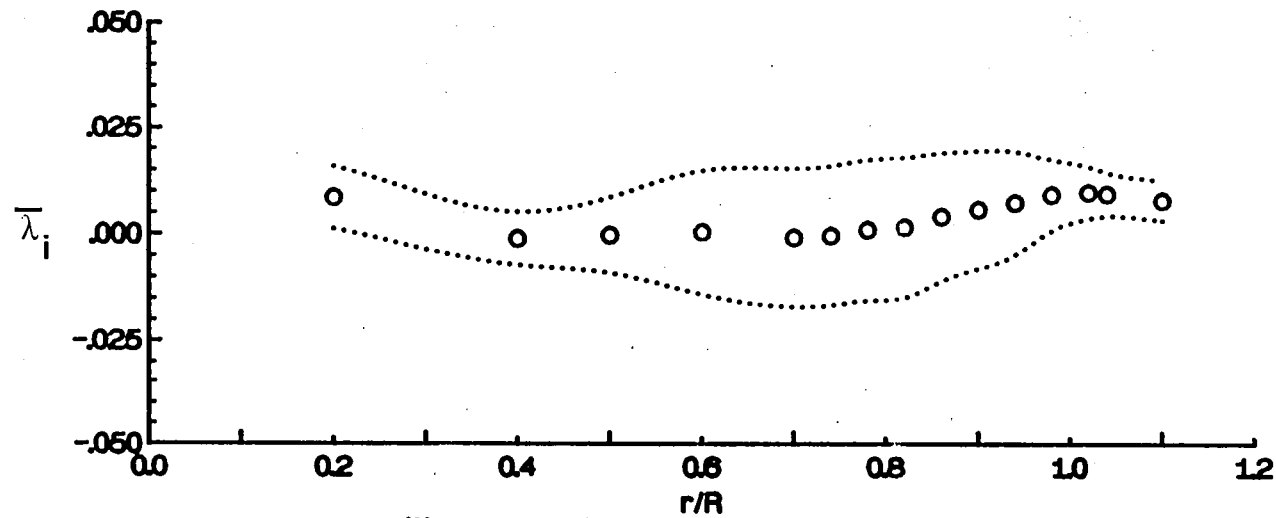
Figure 10.- Continued.



(g) rotor azimuth = 180 degrees

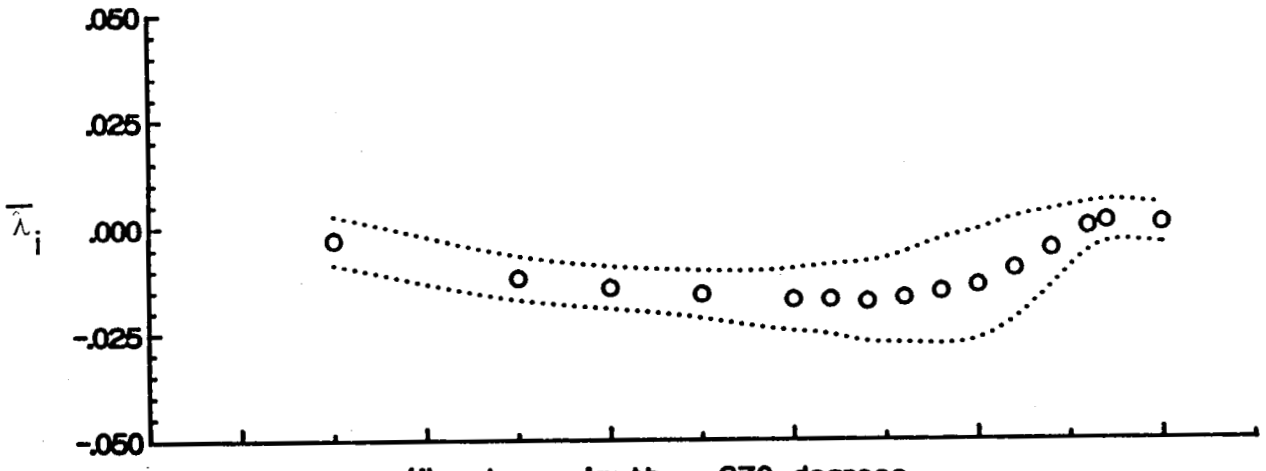


(h) rotor azimuth = 210 degrees

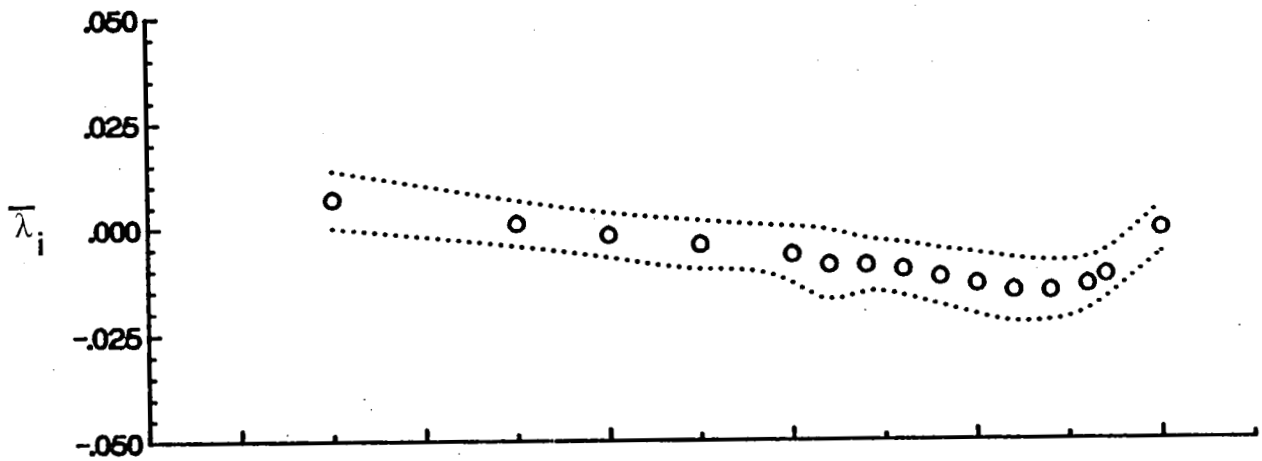


(i) rotor azimuth = 240 degrees

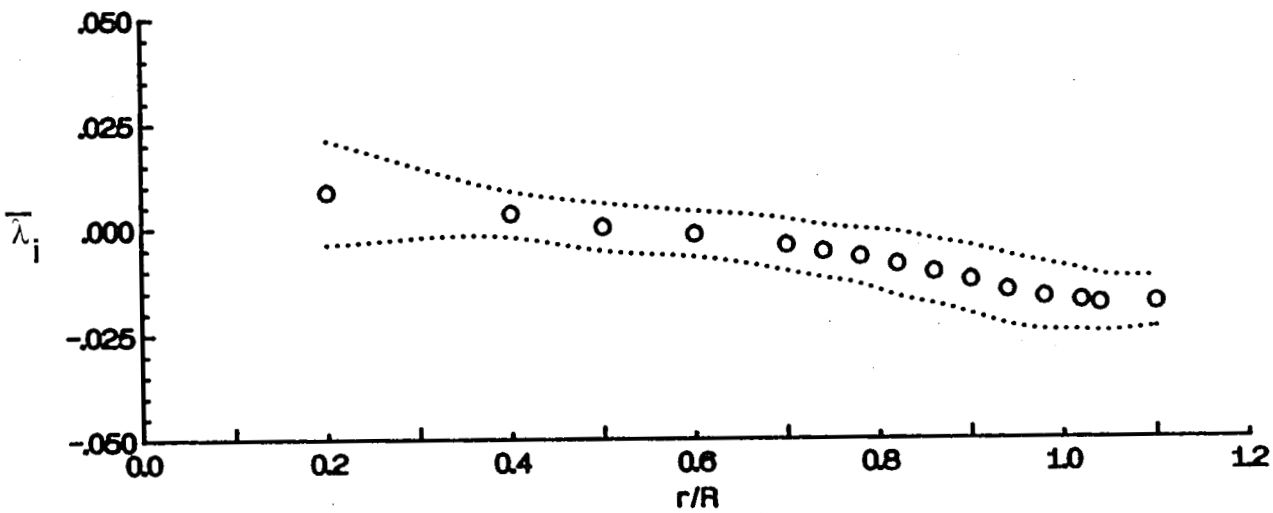
Figure 10.- Continued.



(j) rotor azimuth = 270 degrees



(k) rotor azimuth = 300 degrees



(l) rotor azimuth = 330 degrees

Figure 10.- Concluded.

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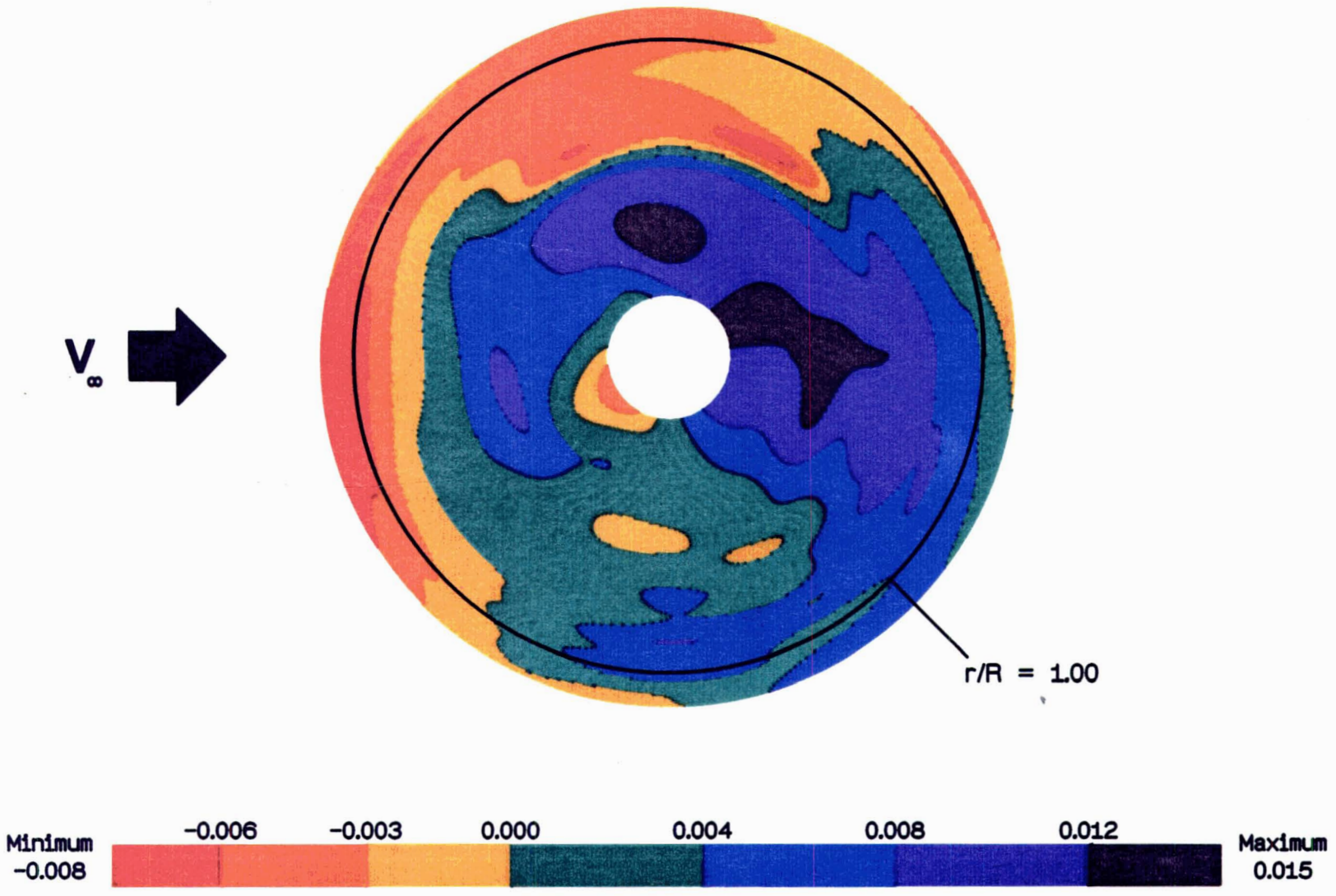


Figure 11. Contour plot of mean induced inflow ratio $\overline{\mu}_i$

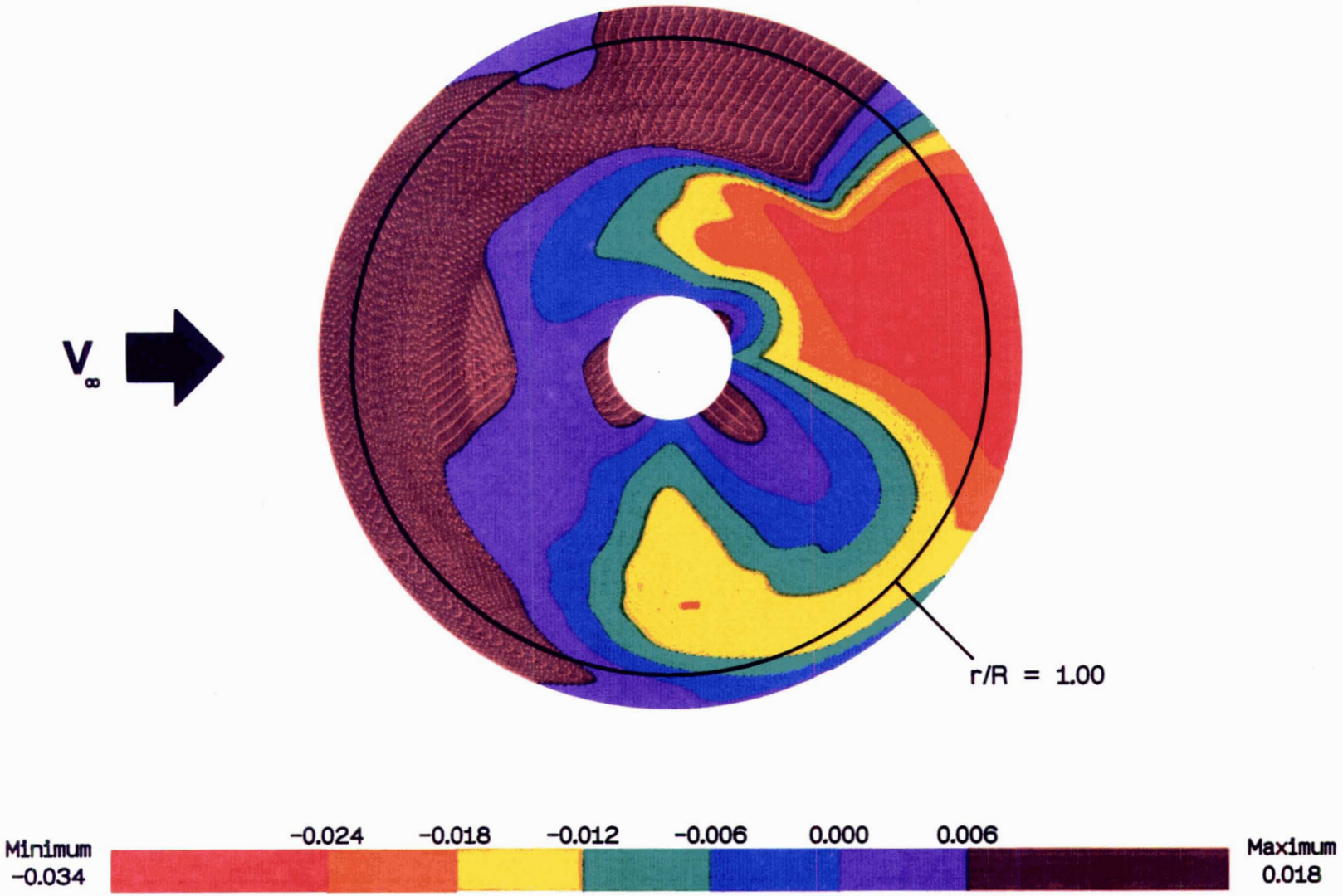


Figure 12. Contour plot of mean induced inflow ratio $\overline{\lambda}_i$

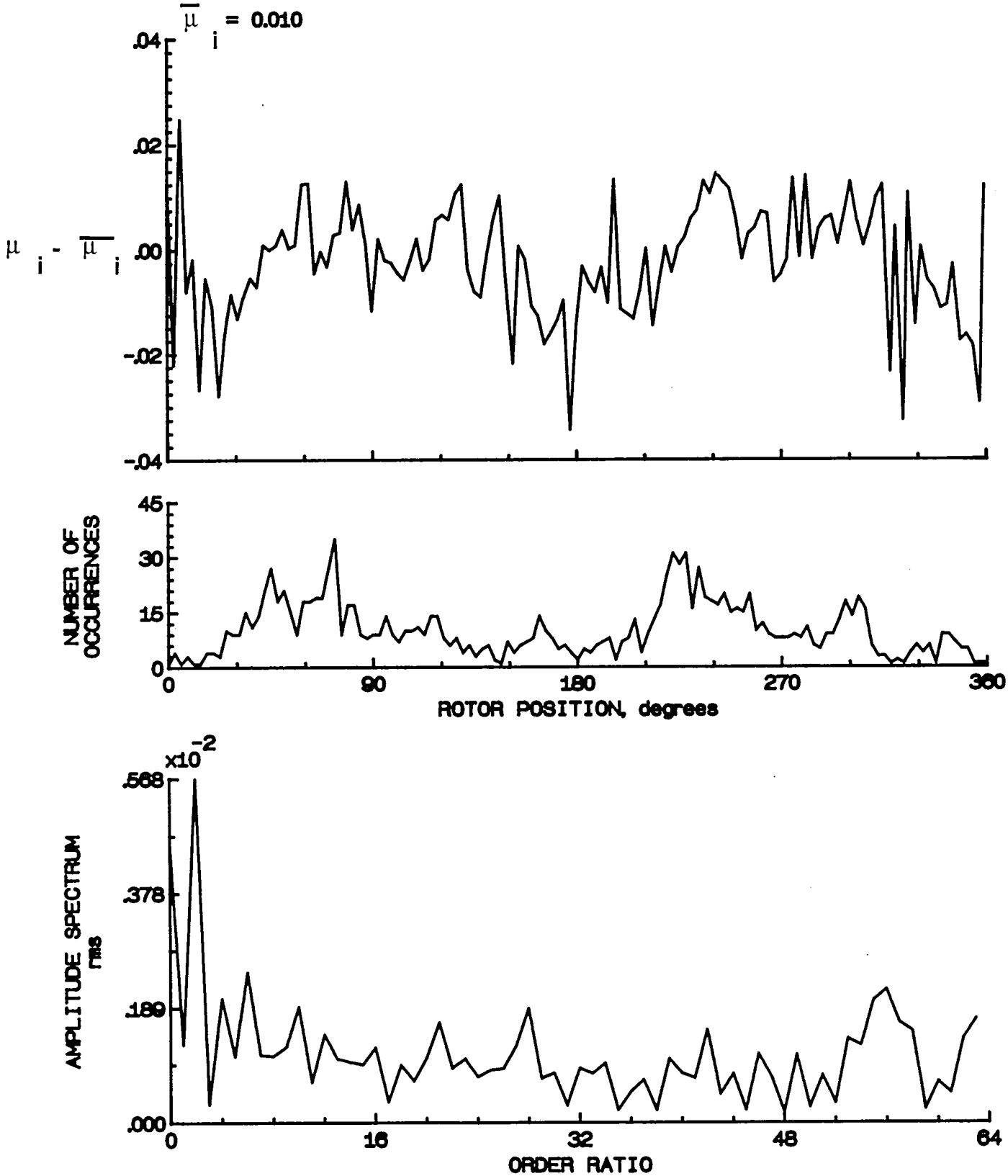
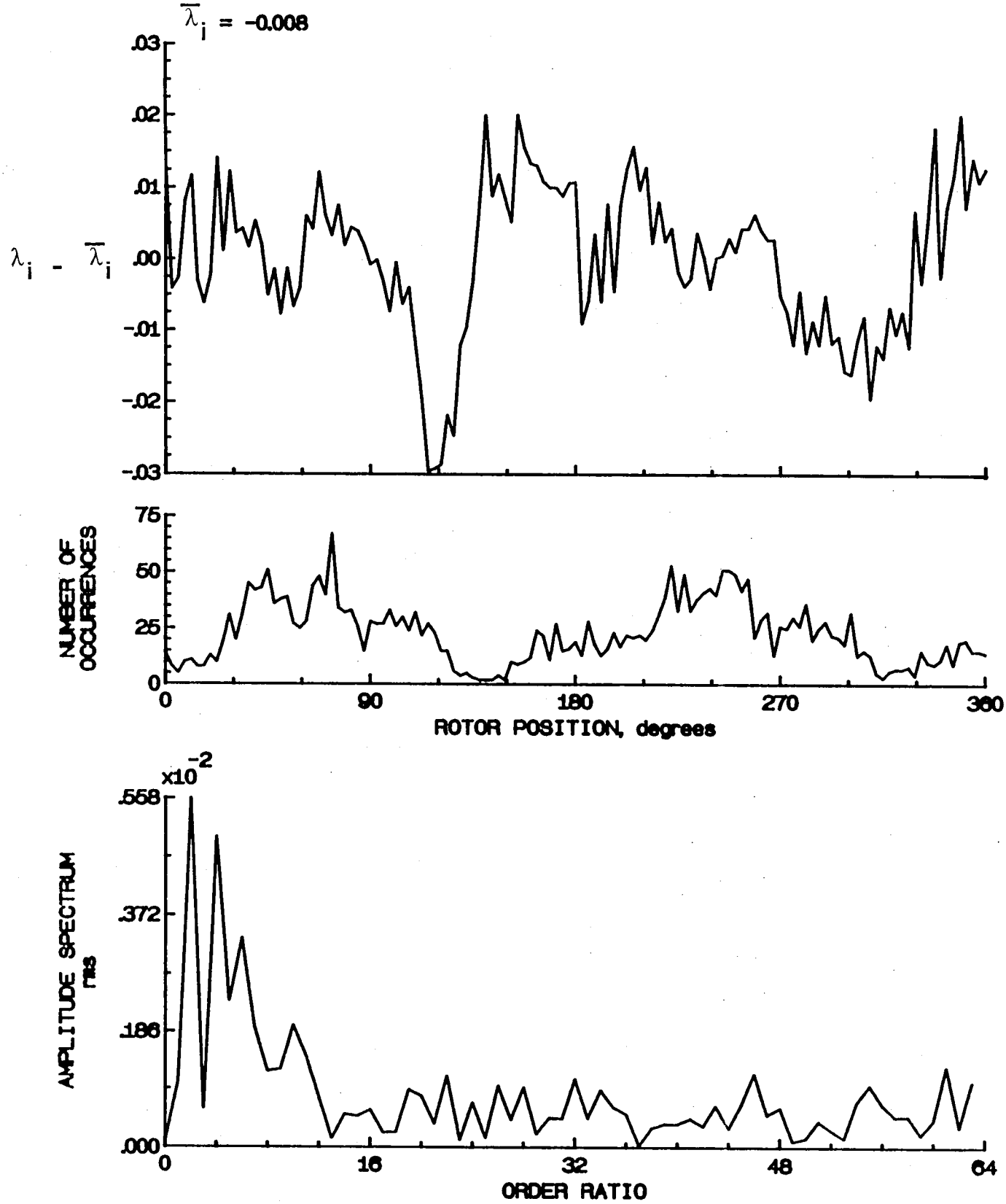


Figure 13.- Induced inflow velocity measured at 0 degrees and r/R of 0.20.



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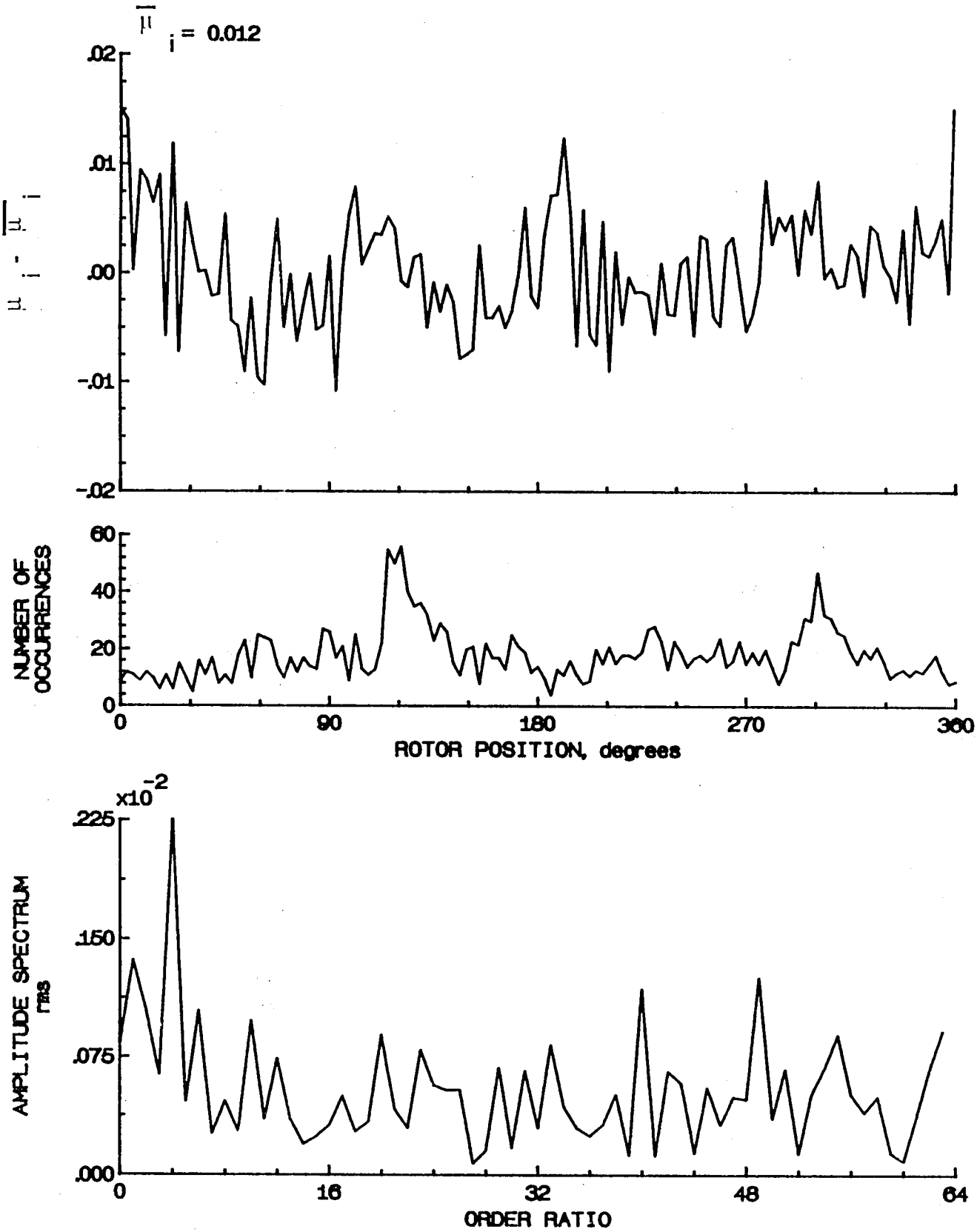
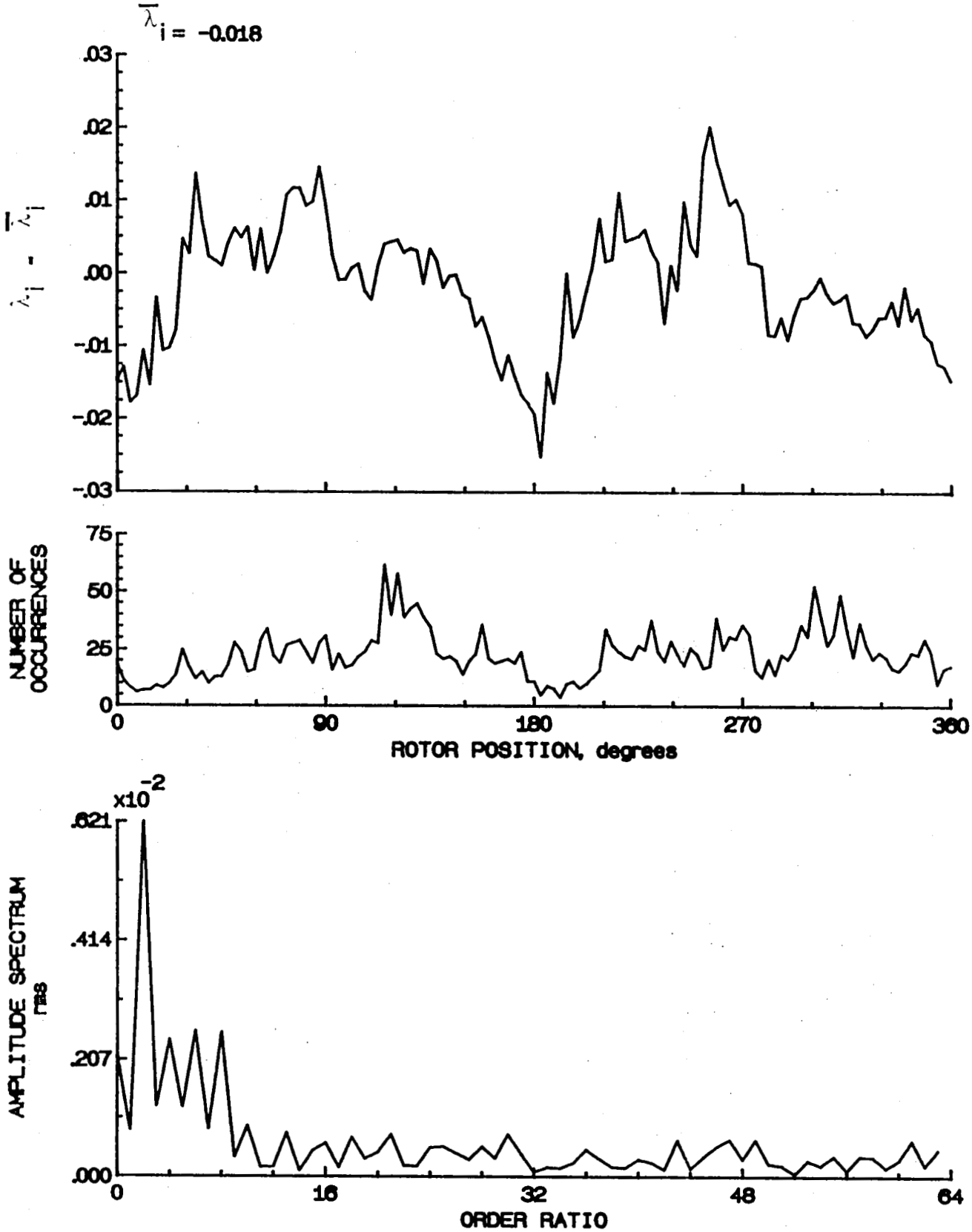


Figure 14.- Induced inflow velocity measured at 0 degrees and r/R of 0.40.



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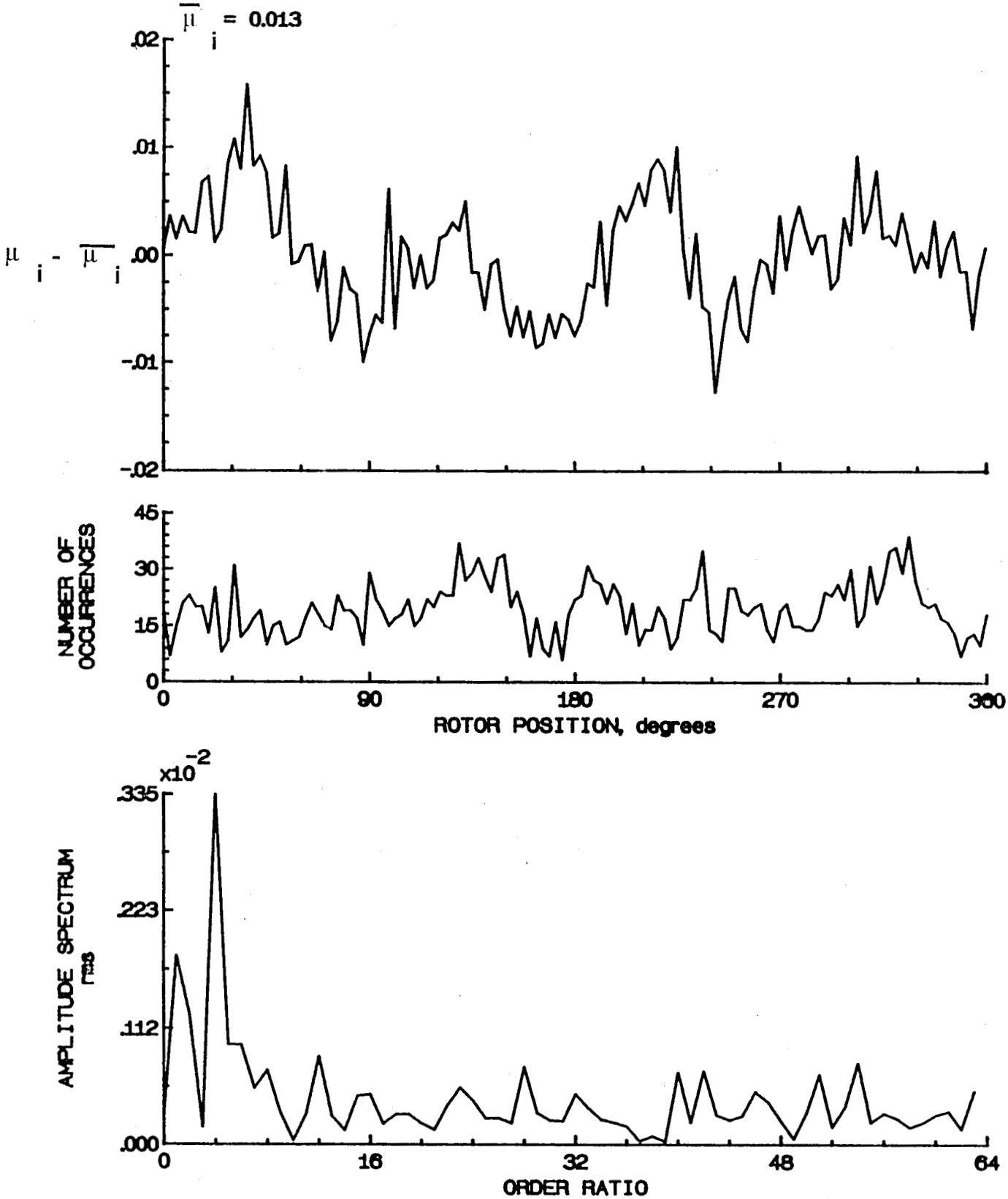
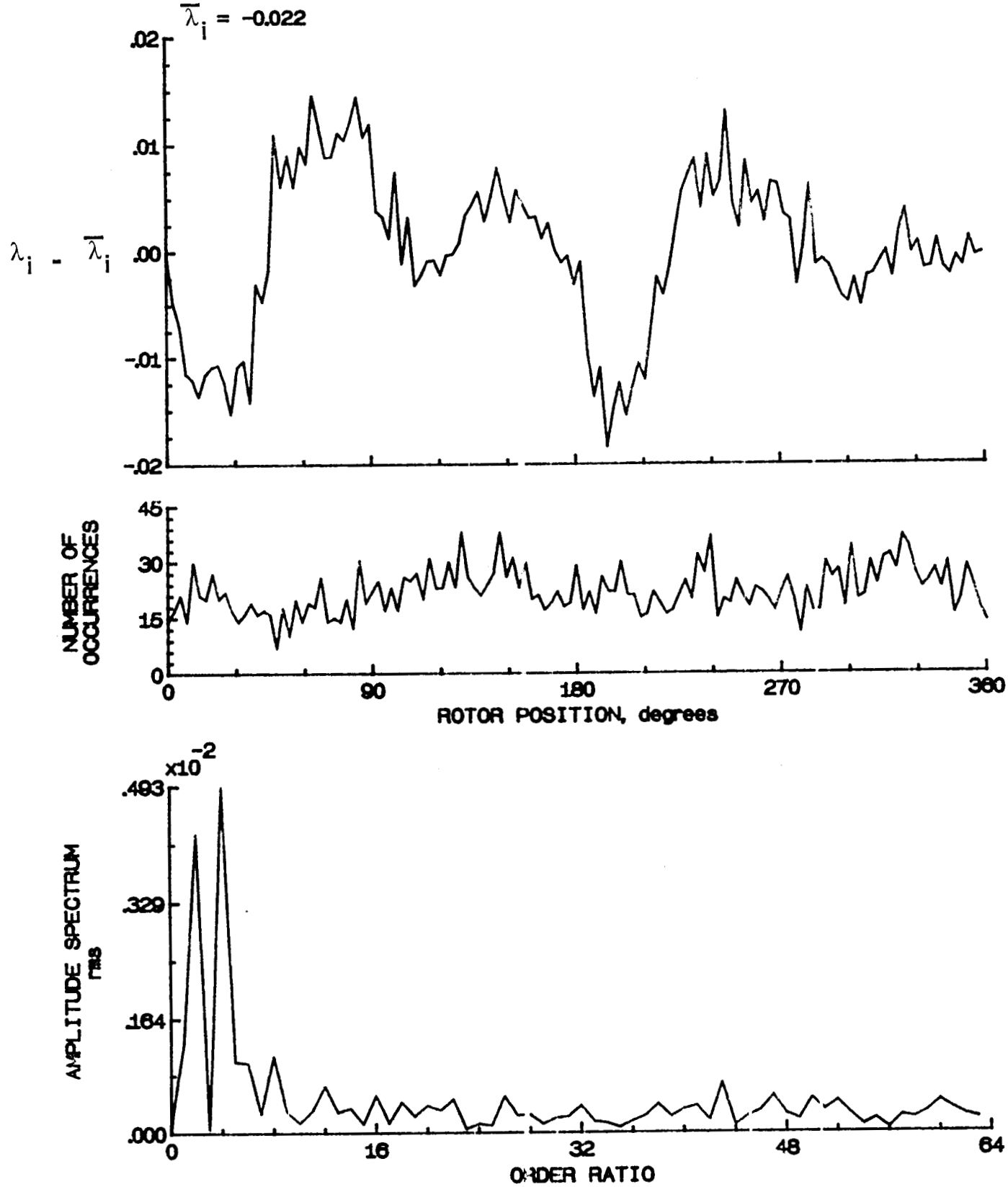


Figure 15.- Induced inflow velocity measured at 0 degrees and r/R of 0.50.



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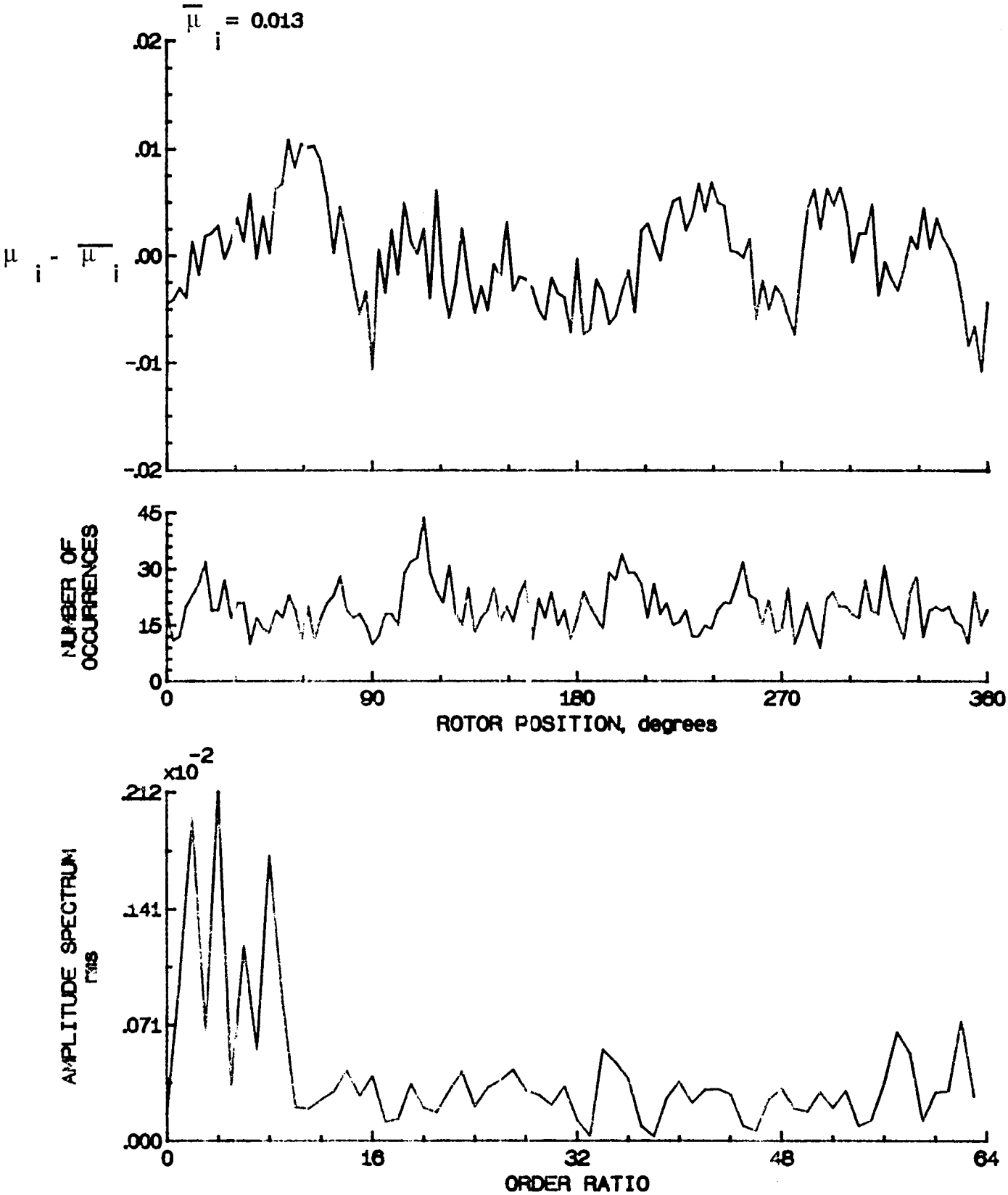
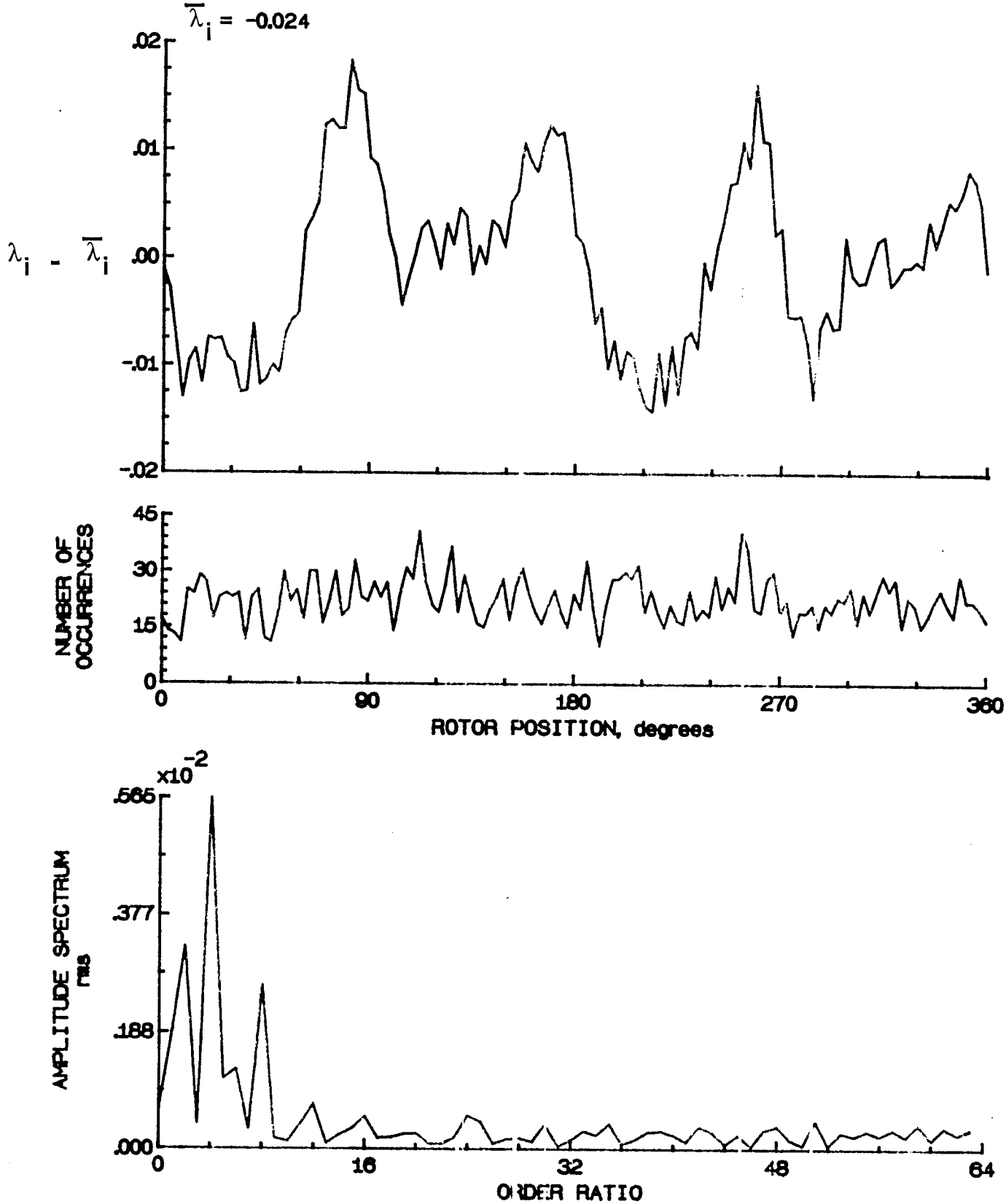


Figure 16.- Induced inflow velocity measured at 0 degrees and r/R of 0.60.



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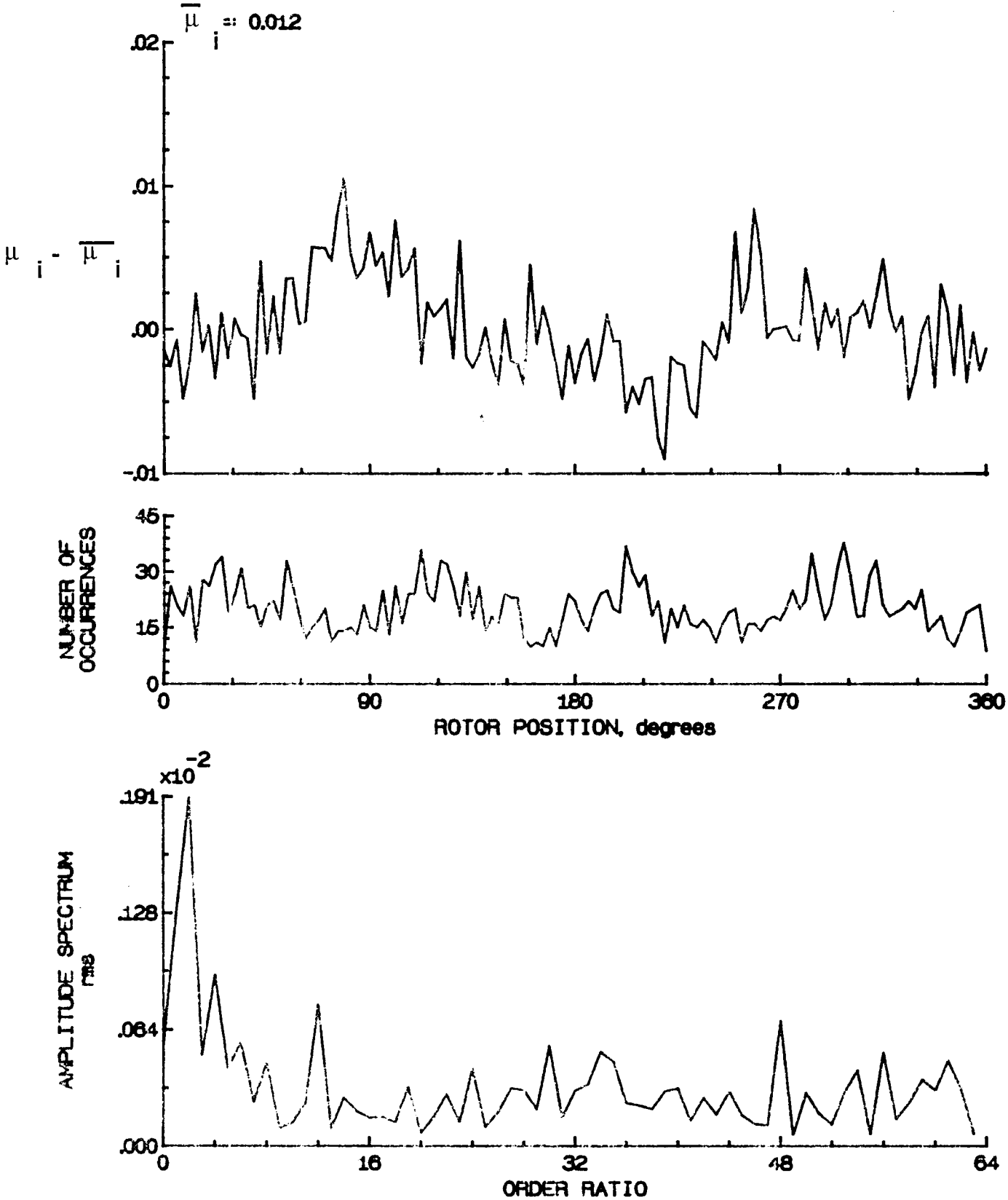
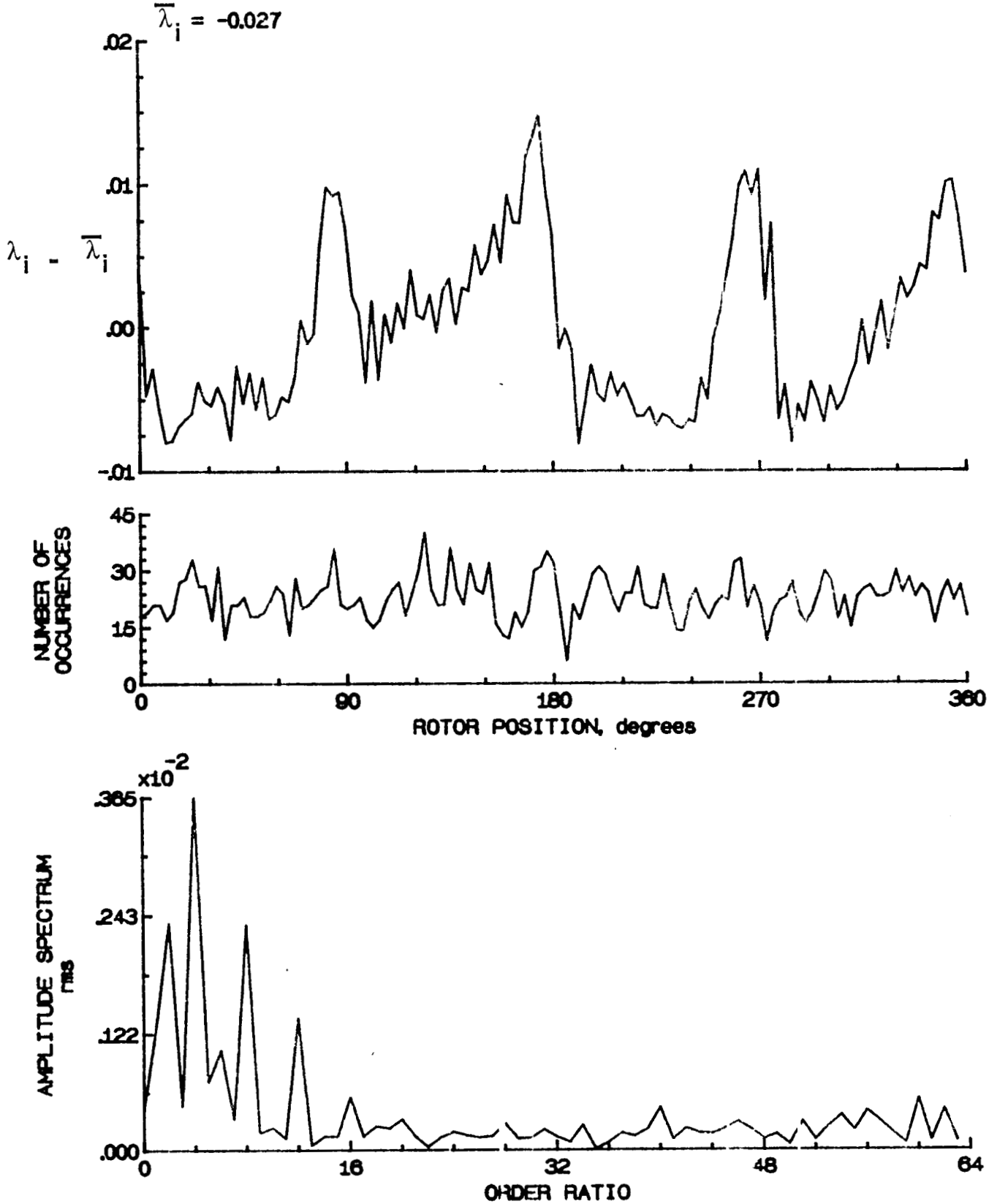


Figure 17.- Induced inflow velocity measured at 0 degrees and r/R of 0.70.



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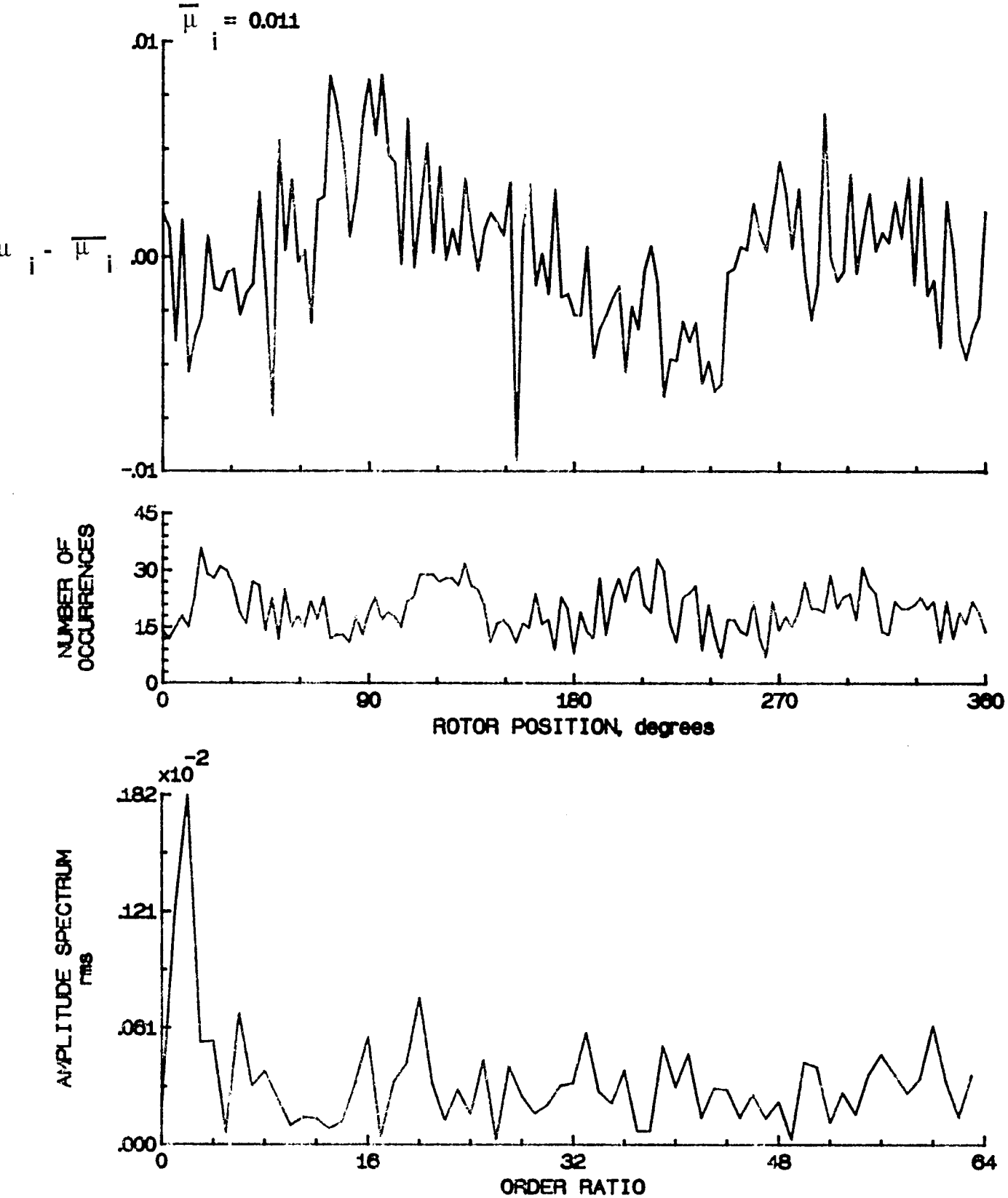
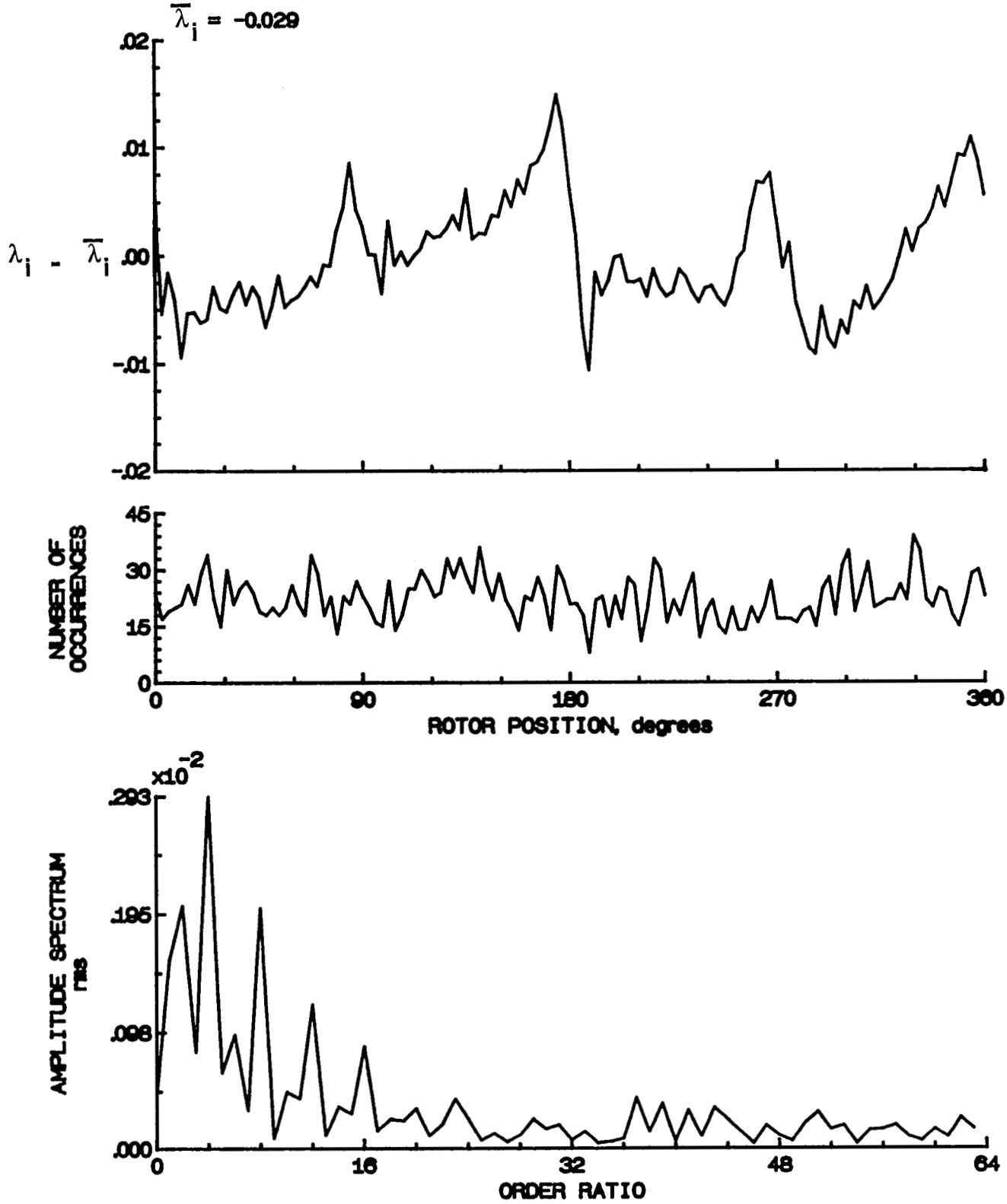


Figure 18.- Induced inflow velocity measured at 0 degrees and r/R of 0.74.



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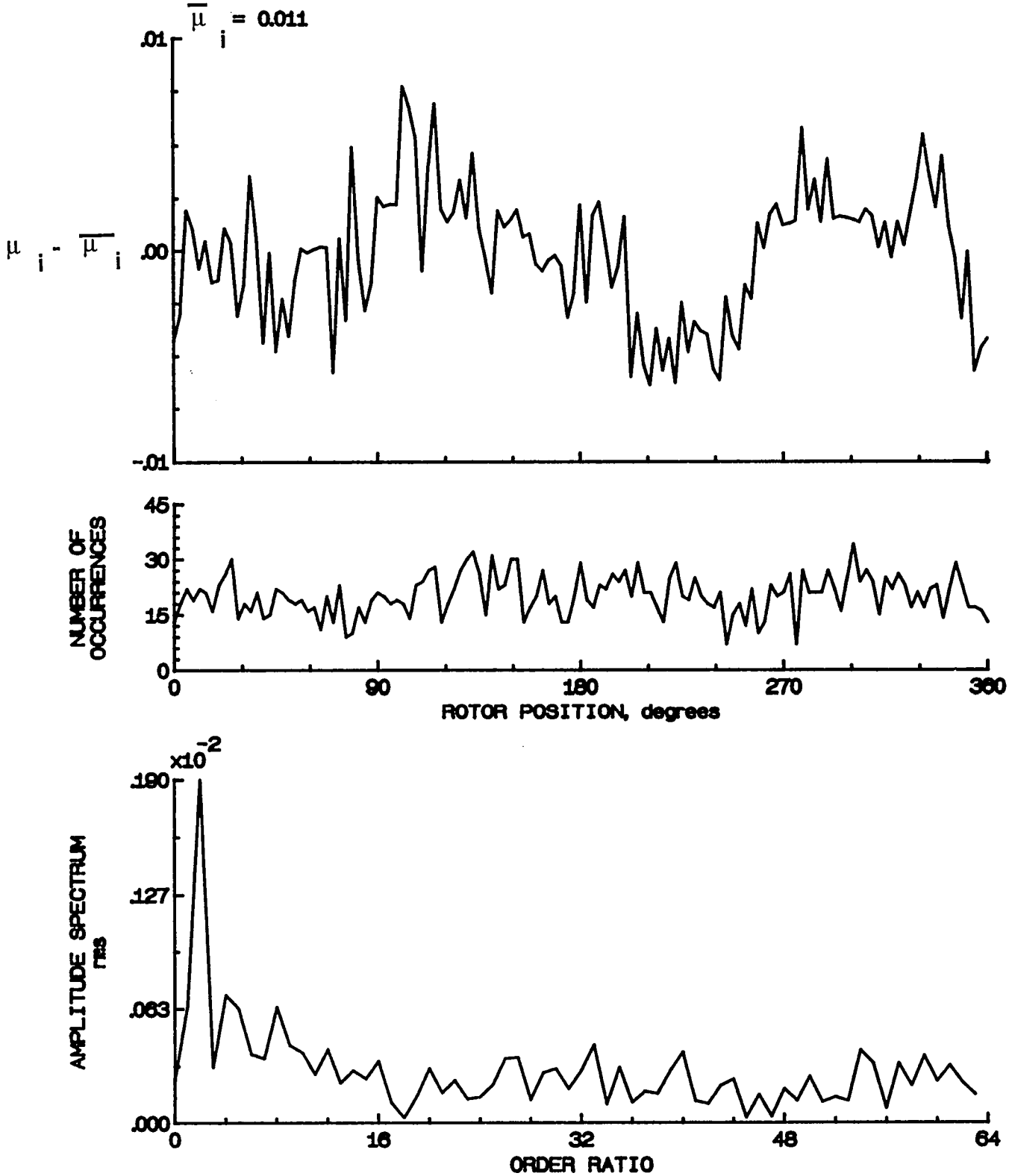
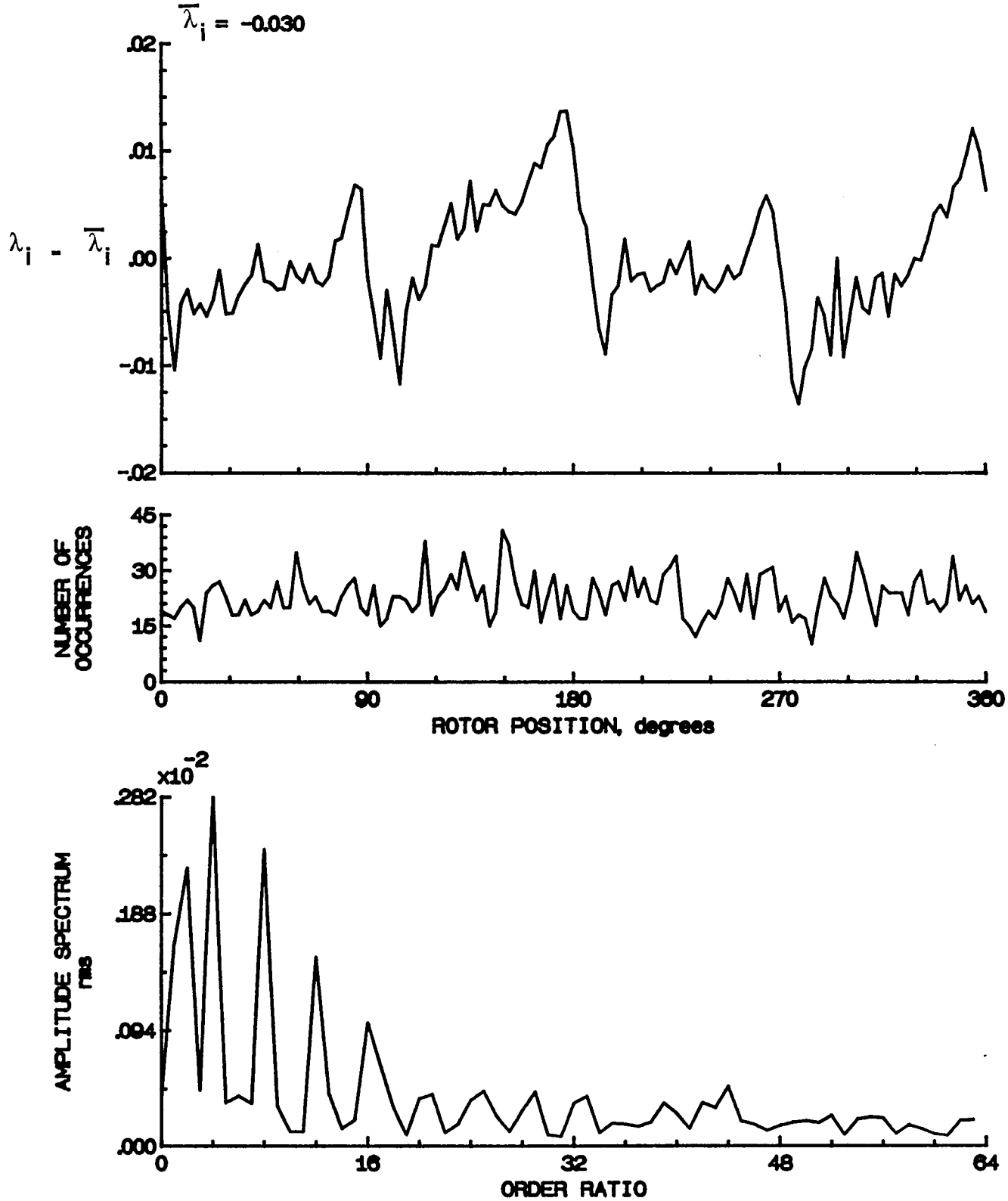


Figure 19.- Induced inflow velocity measured at 0 degrees and r/R of 0.78.



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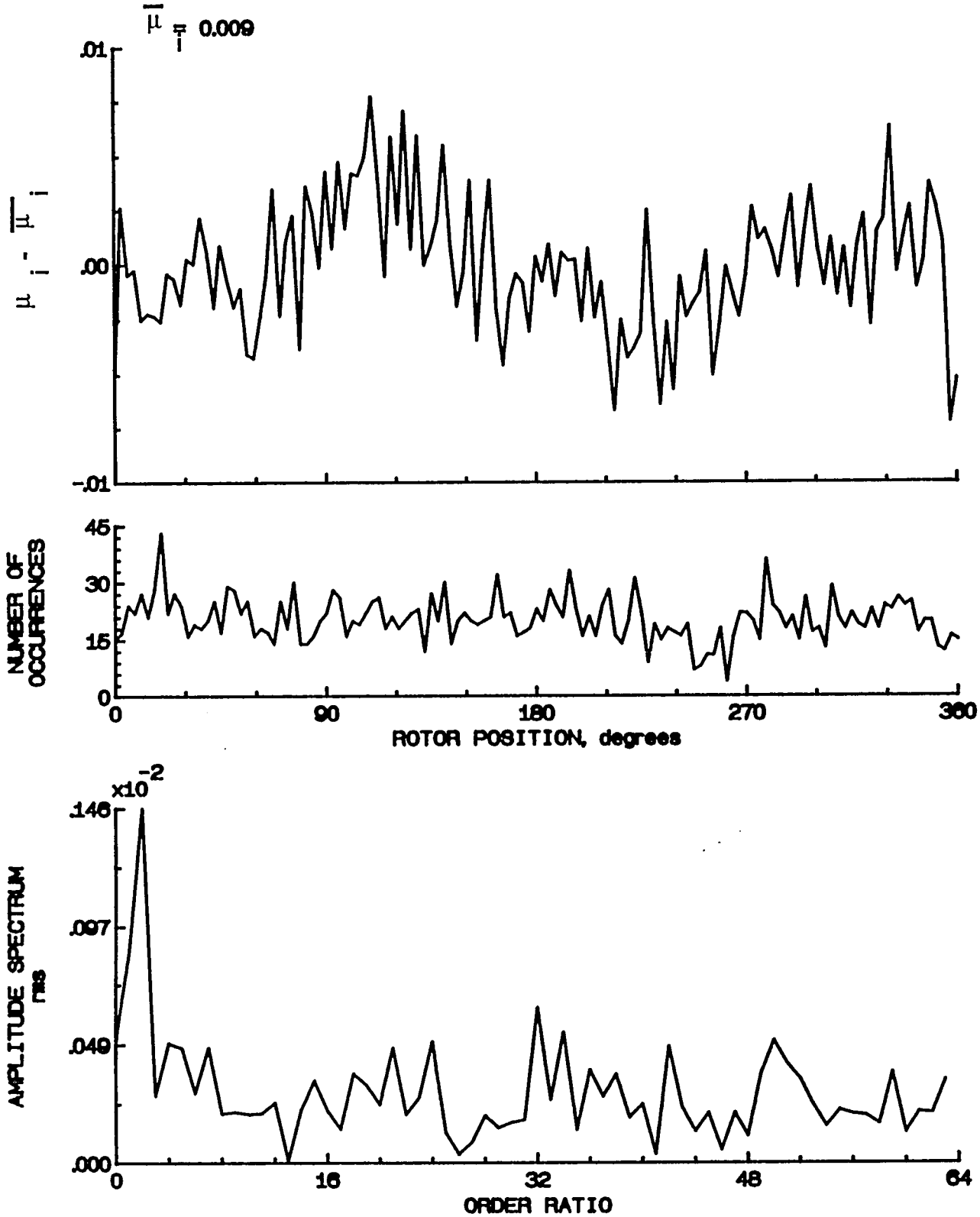
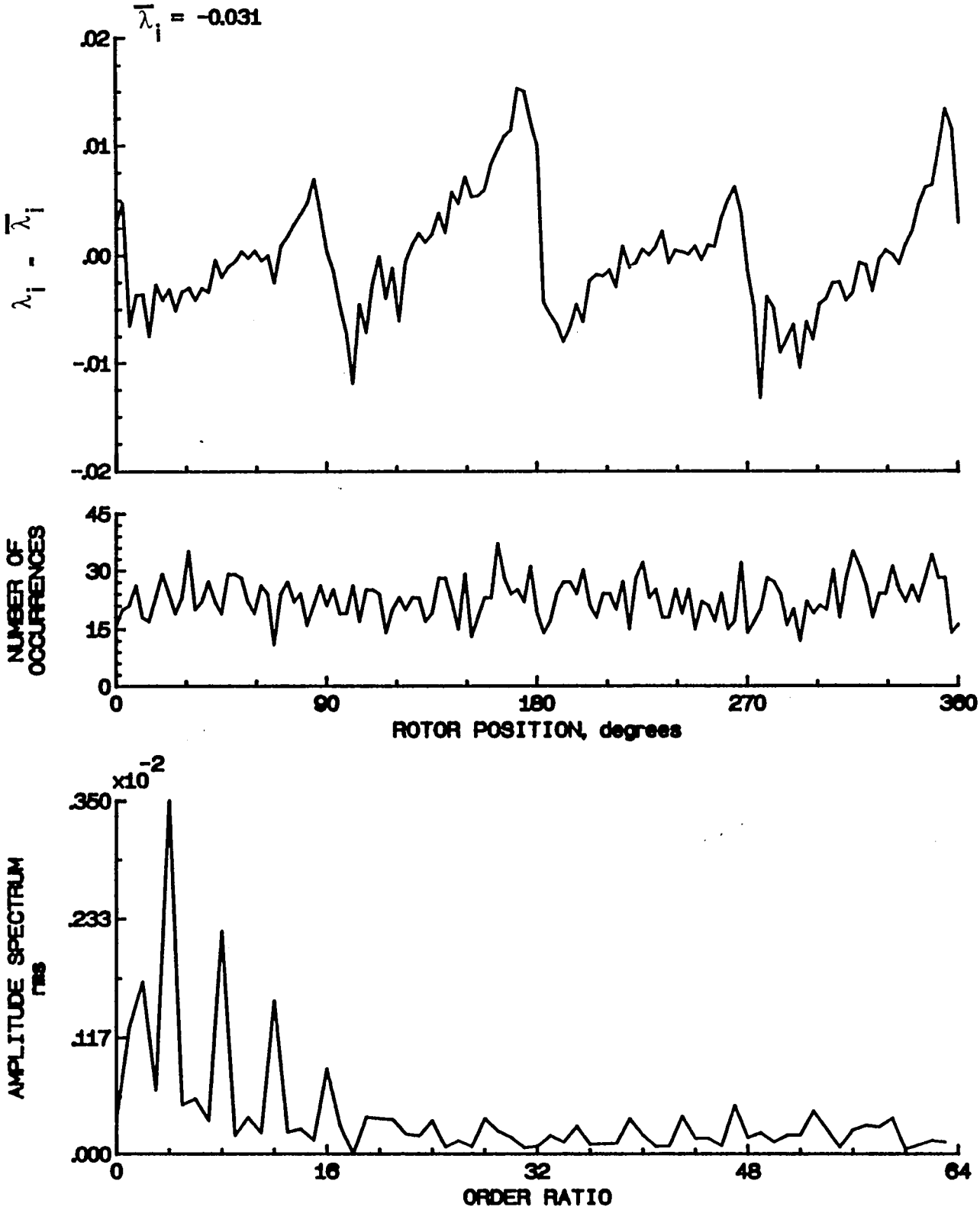


Figure 20.- Induced inflow velocity measured at 0 degrees and r/R of 0.82.



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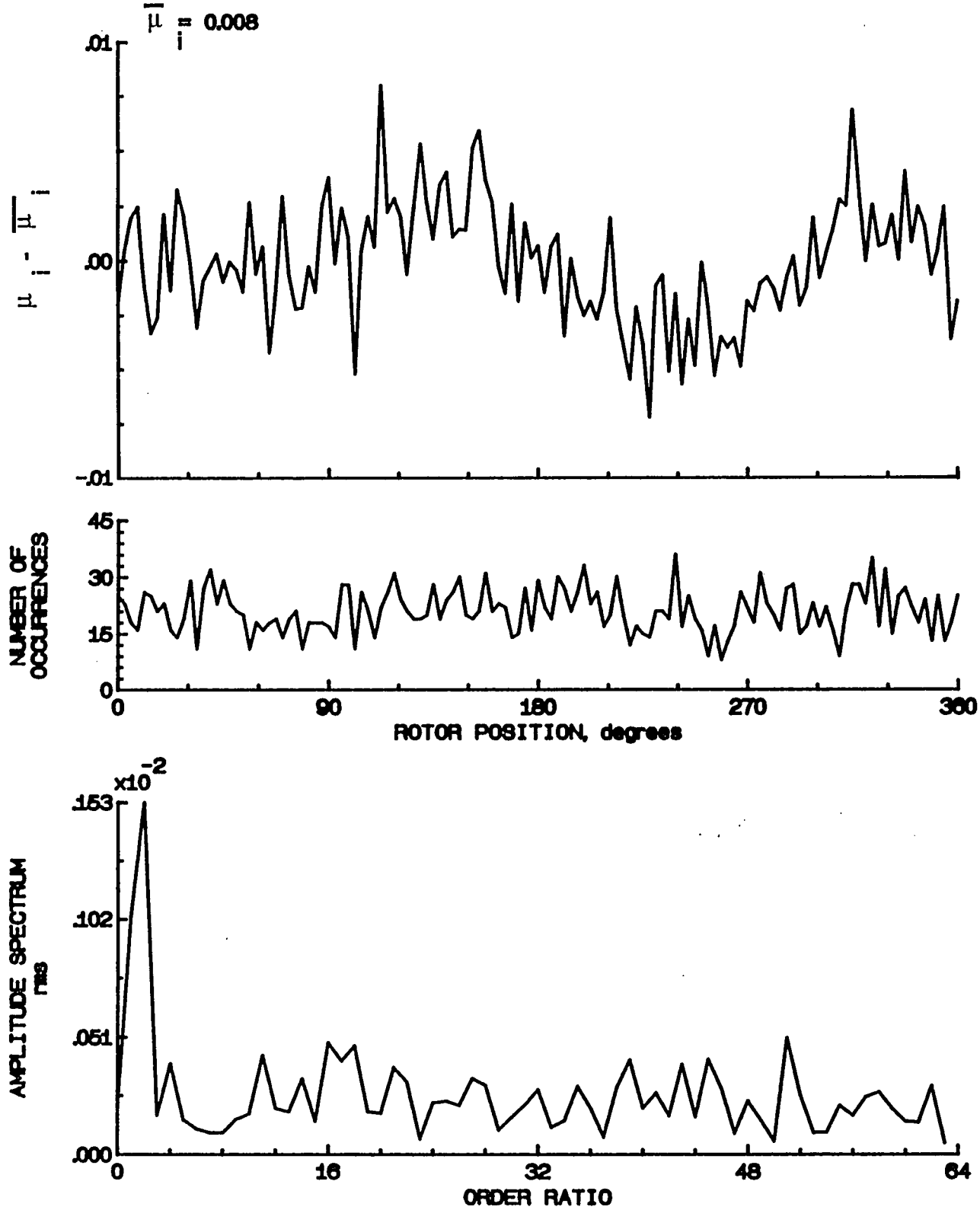
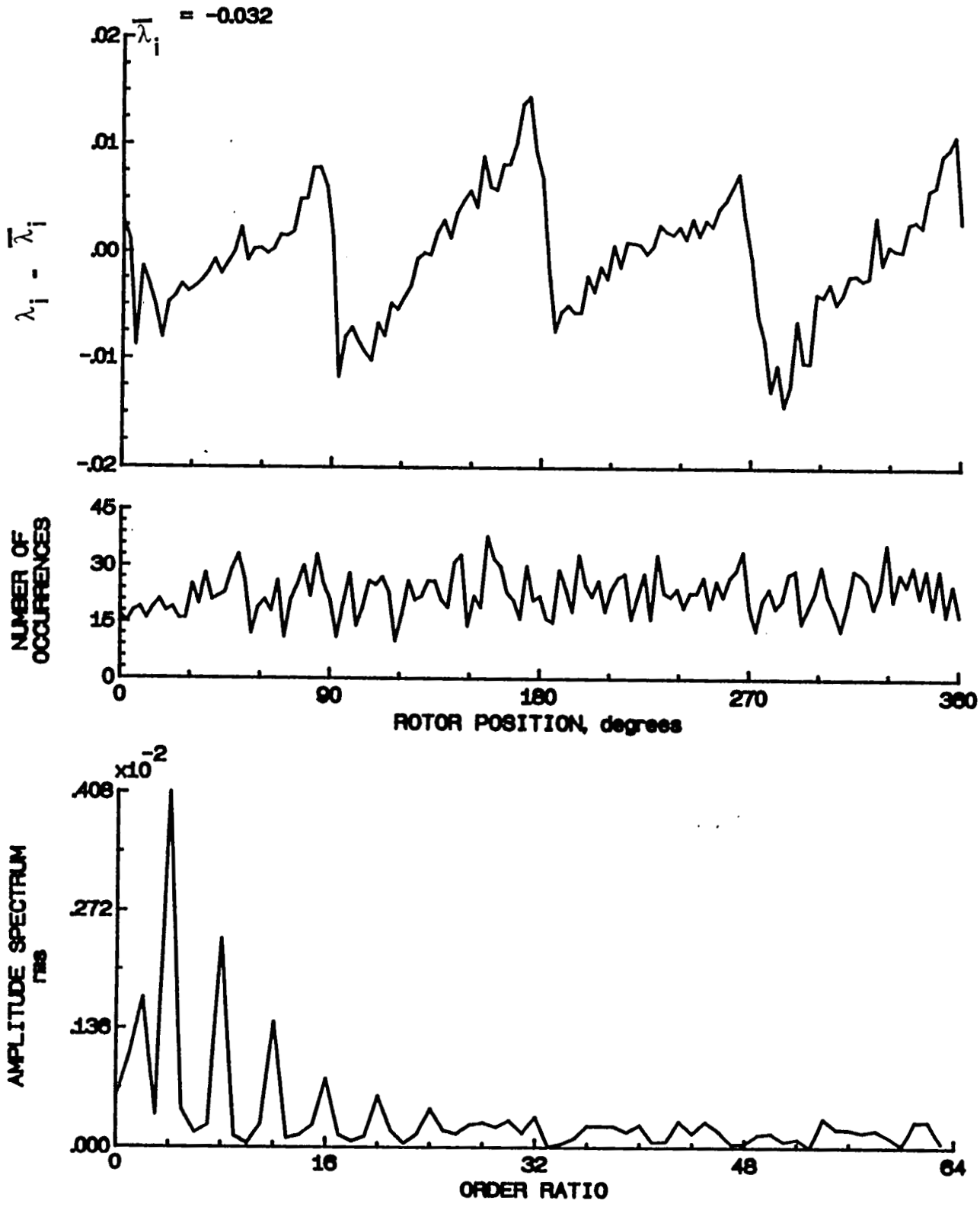


Figure 21.- Induced inflow velocity measured at 0 degrees and r/R of 0.86.



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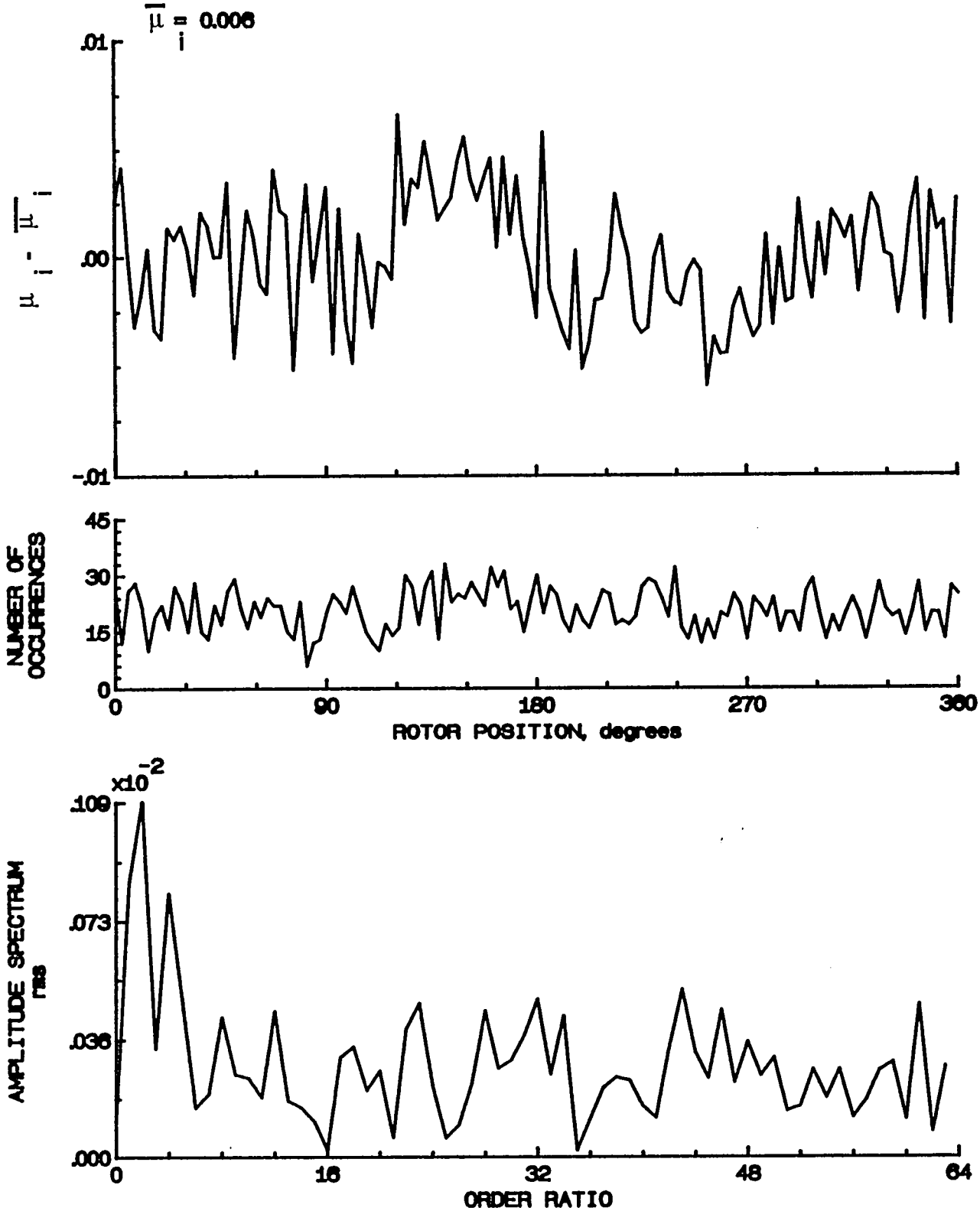
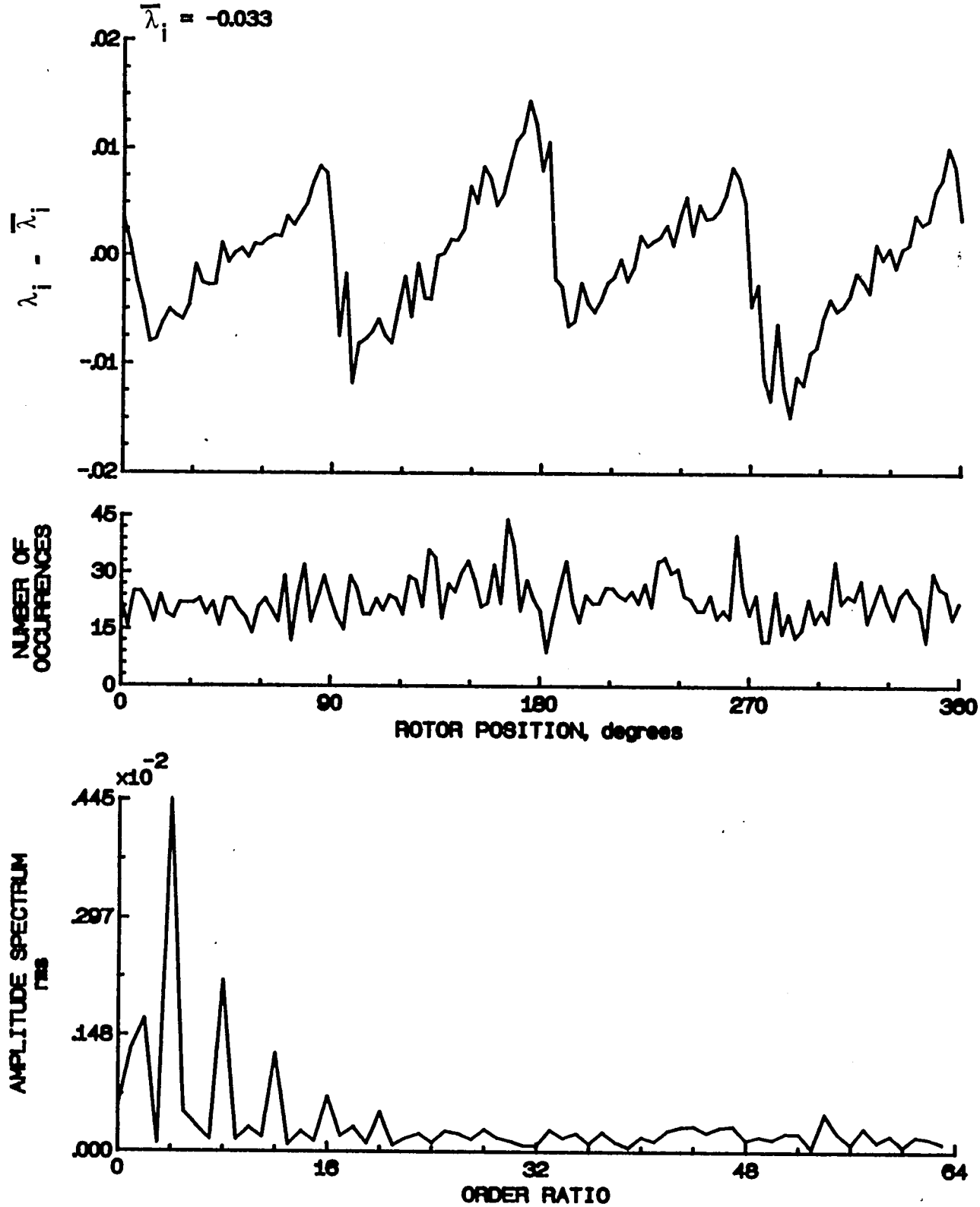


Figure 22.- Induced inflow velocity measured at 0 degrees and r/R of 0.90.



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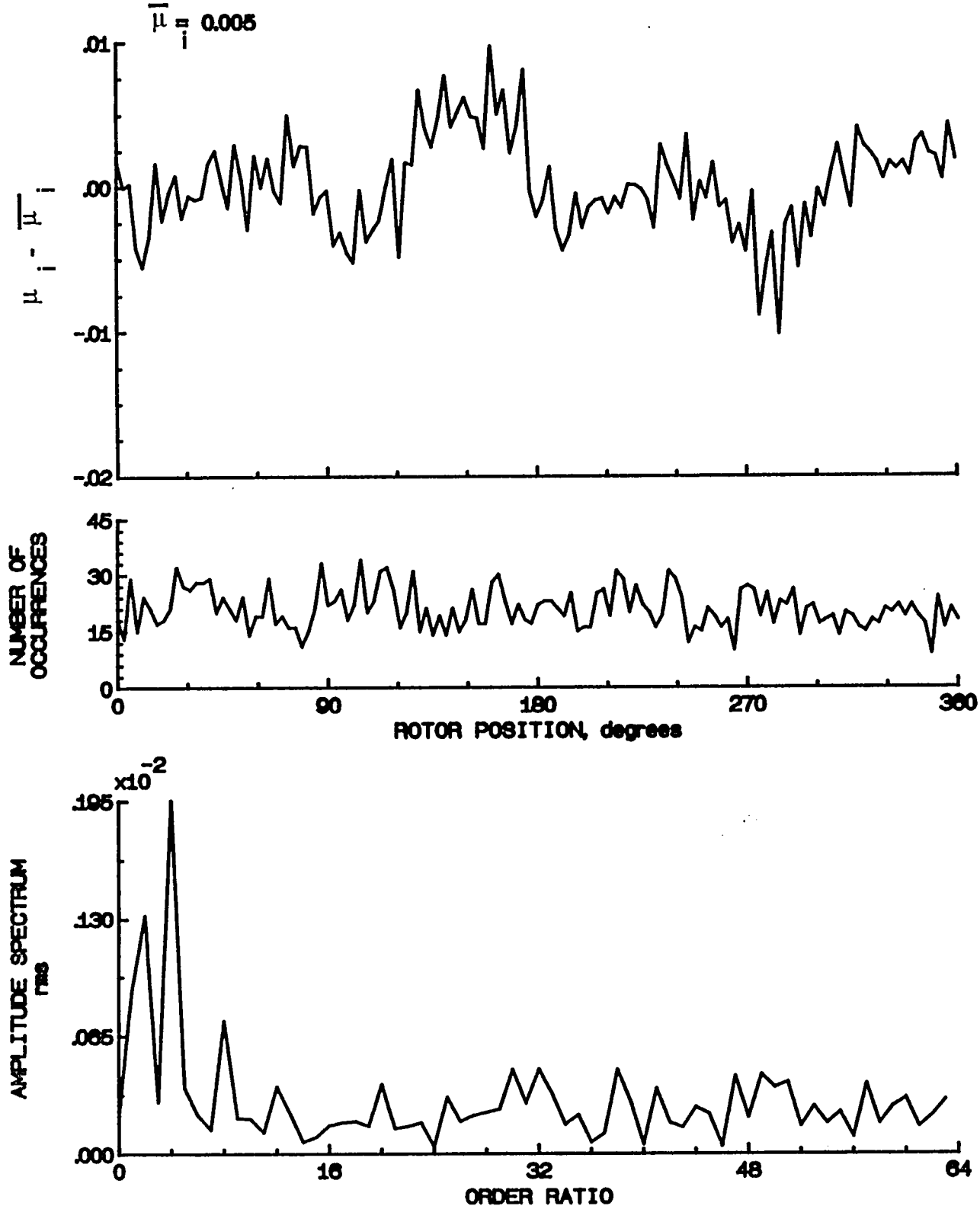
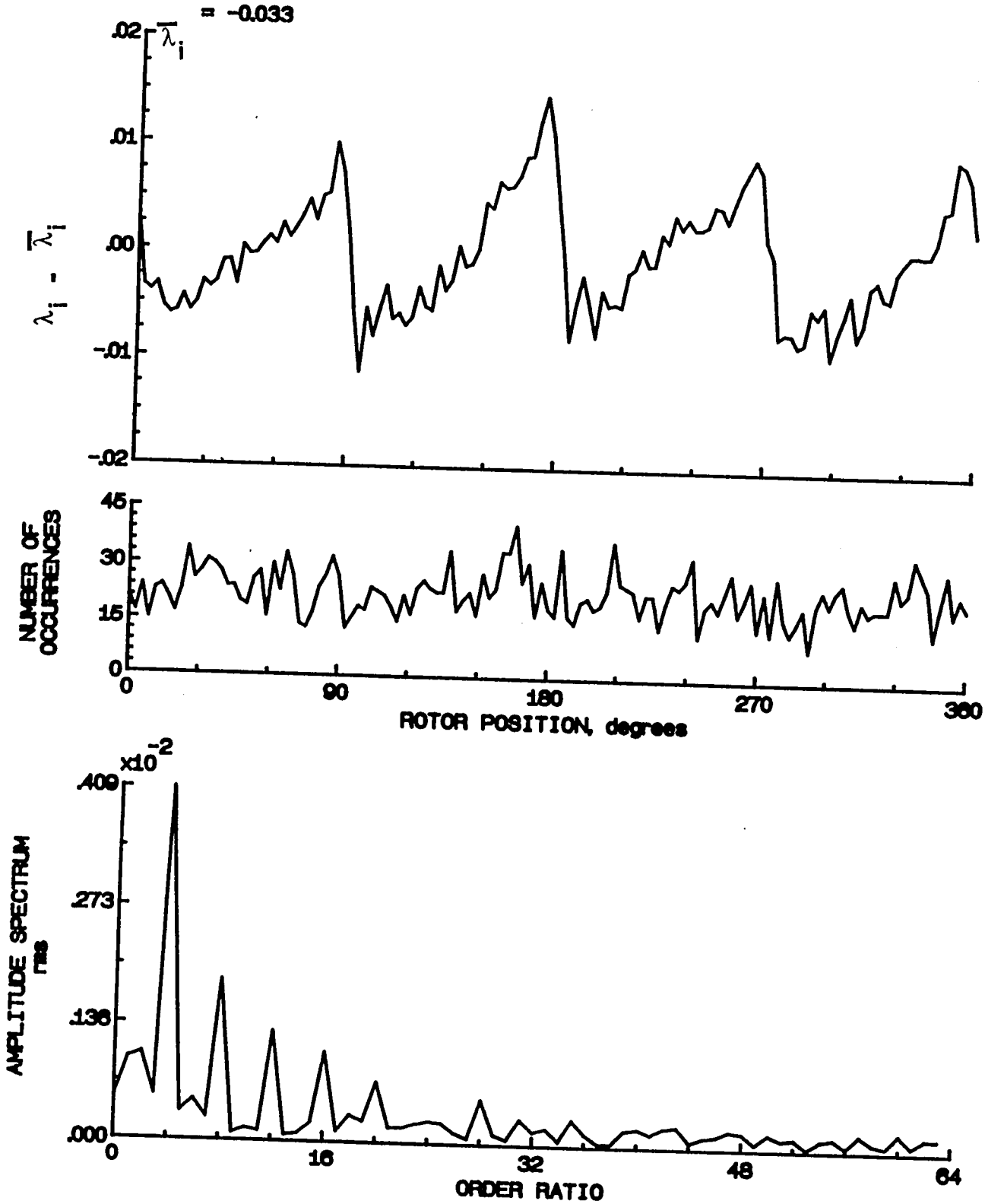


Figure 23.- Induced inflow velocity measured at 0 degrees and r/R of 0.94.



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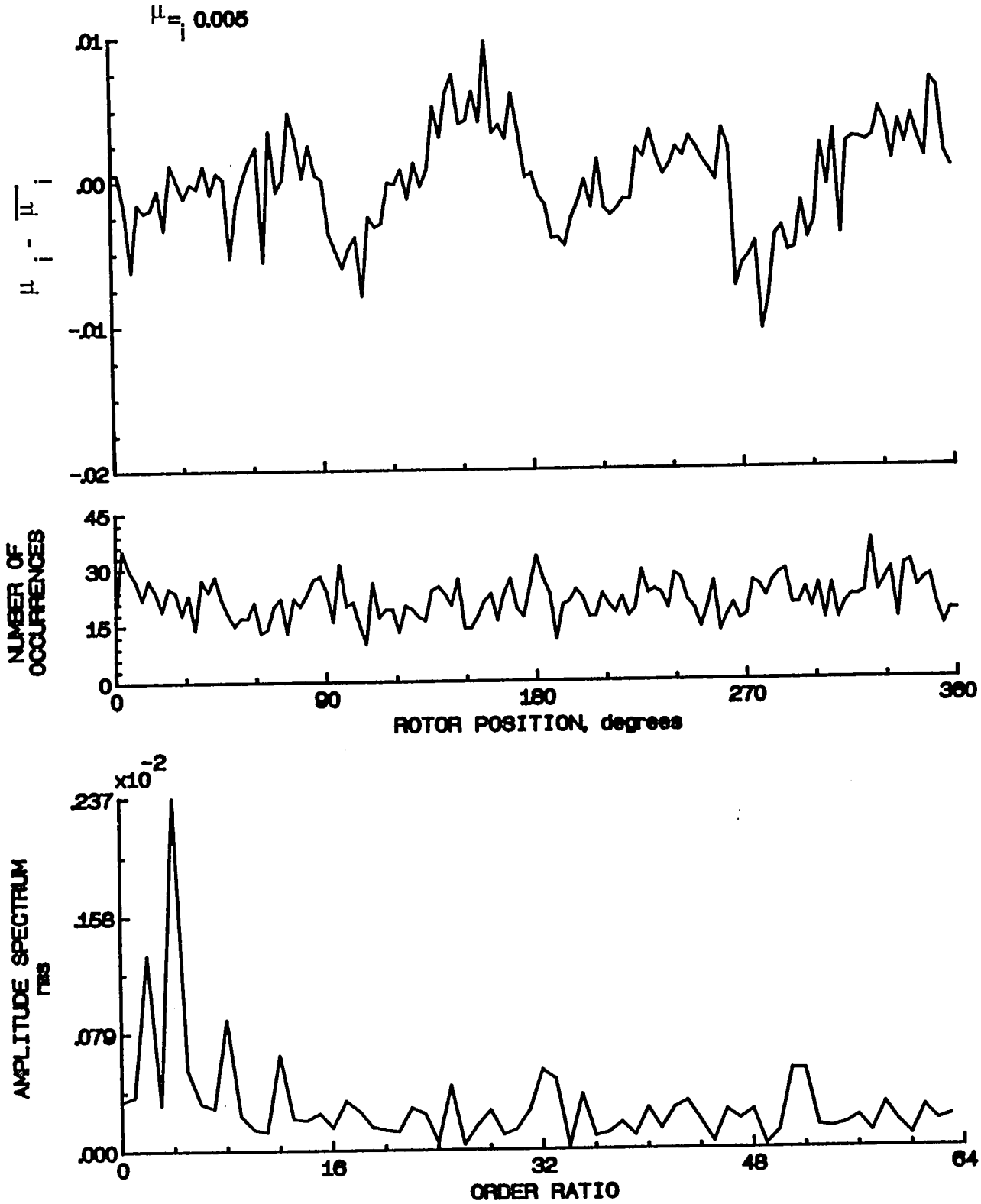
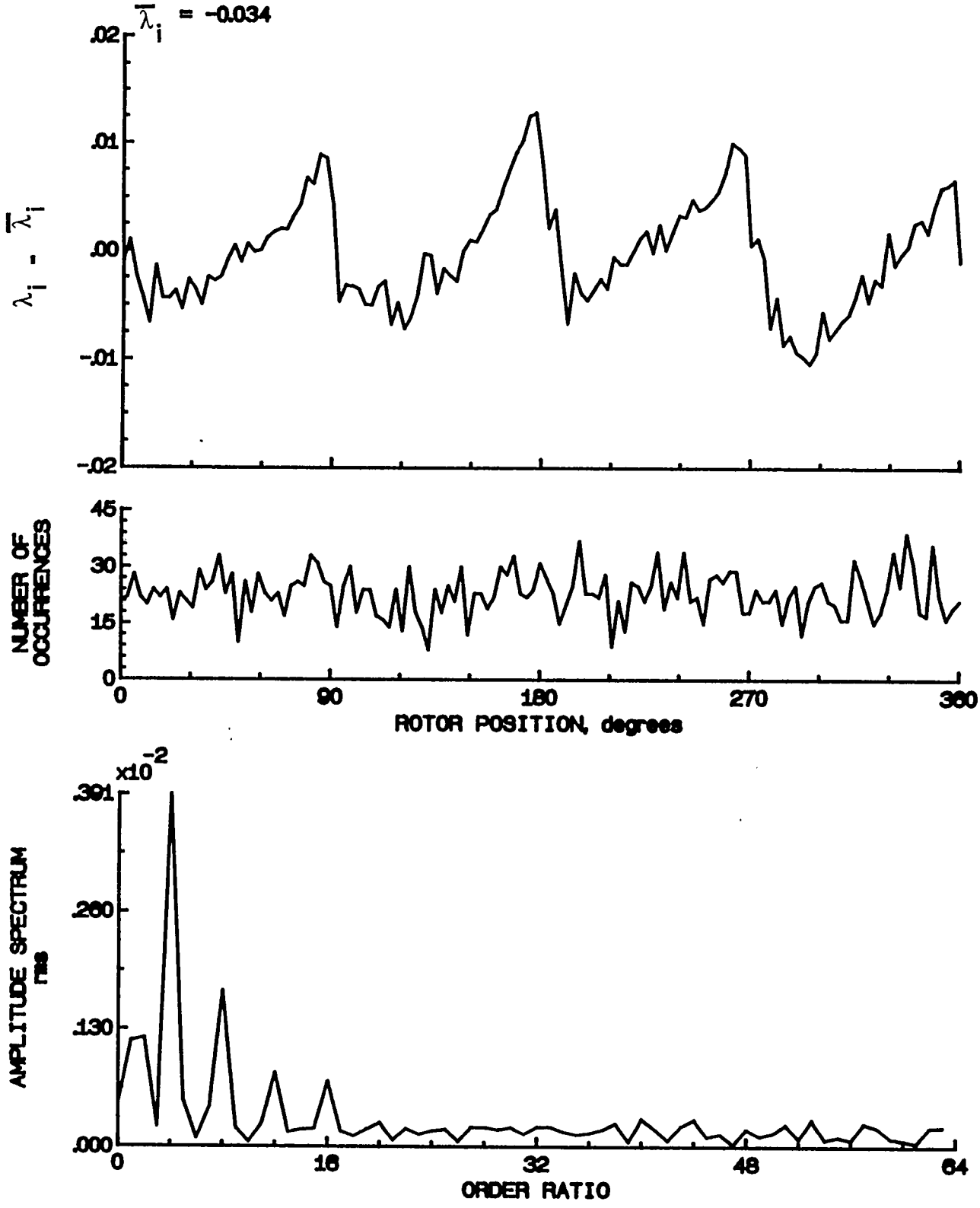


Figure 24.- Induced inflow velocity measured at 0 degrees and r/R of 0.98.



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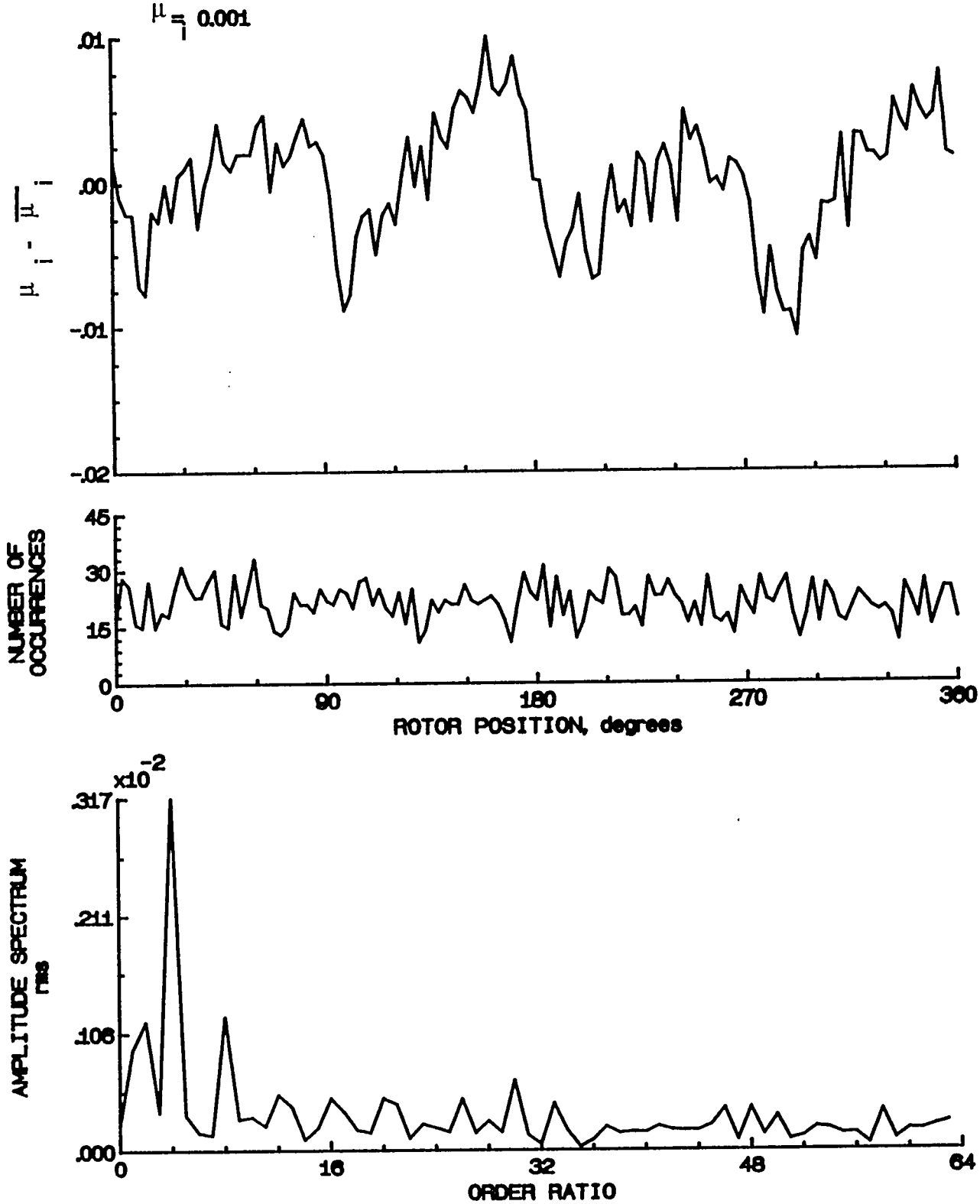
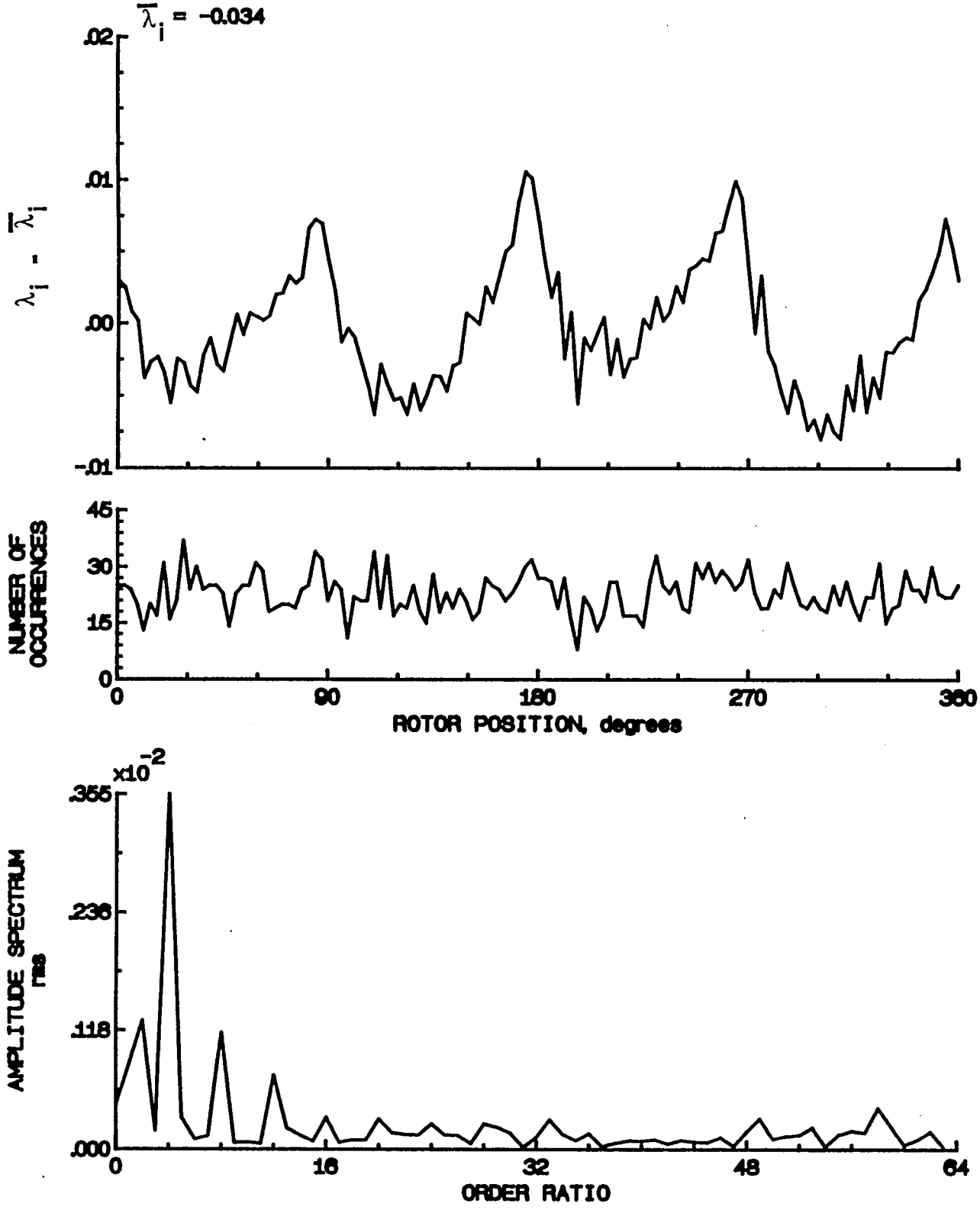


Figure 25.- Induced inflow velocity measured at 0 degrees and r/R of 1.02.



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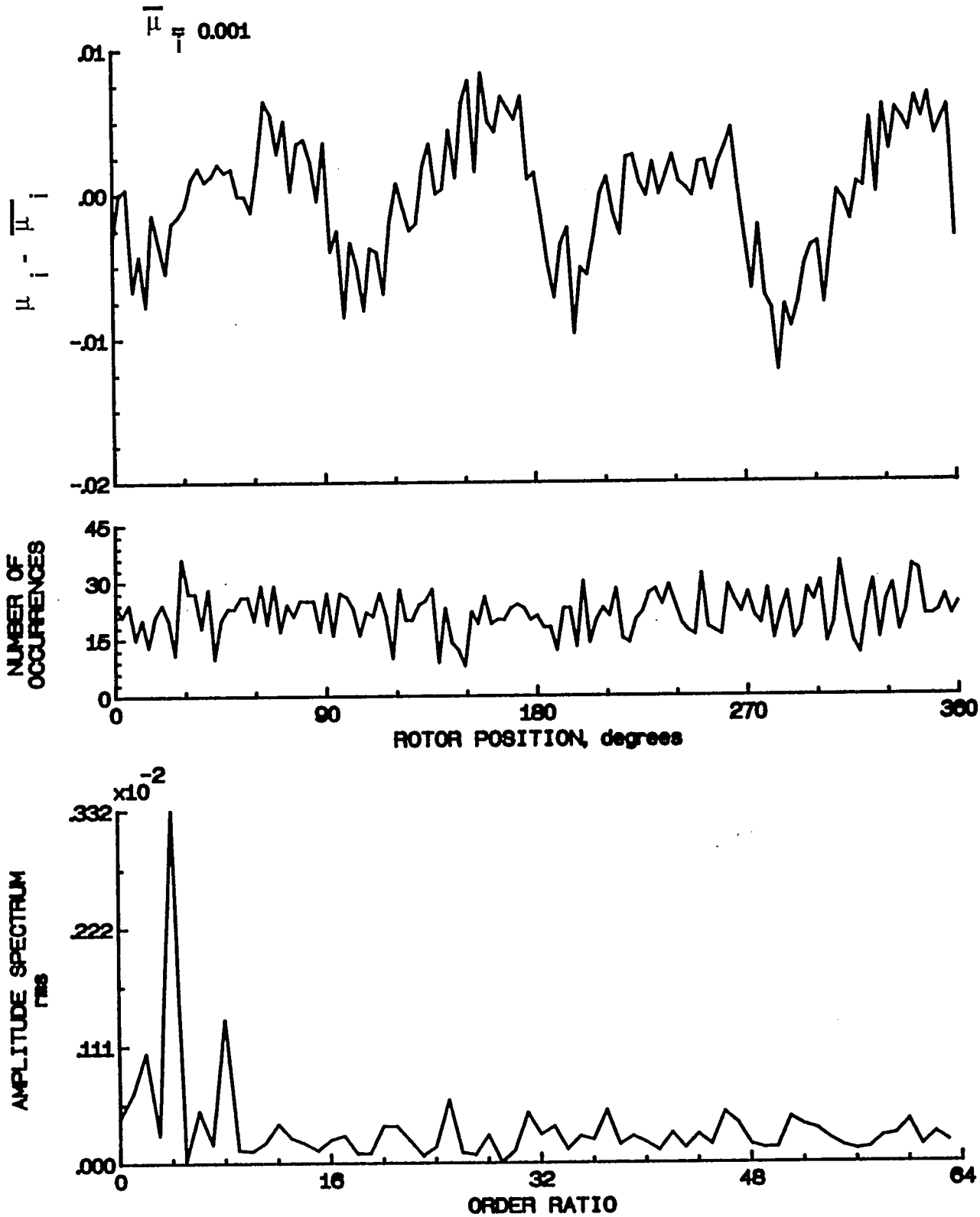
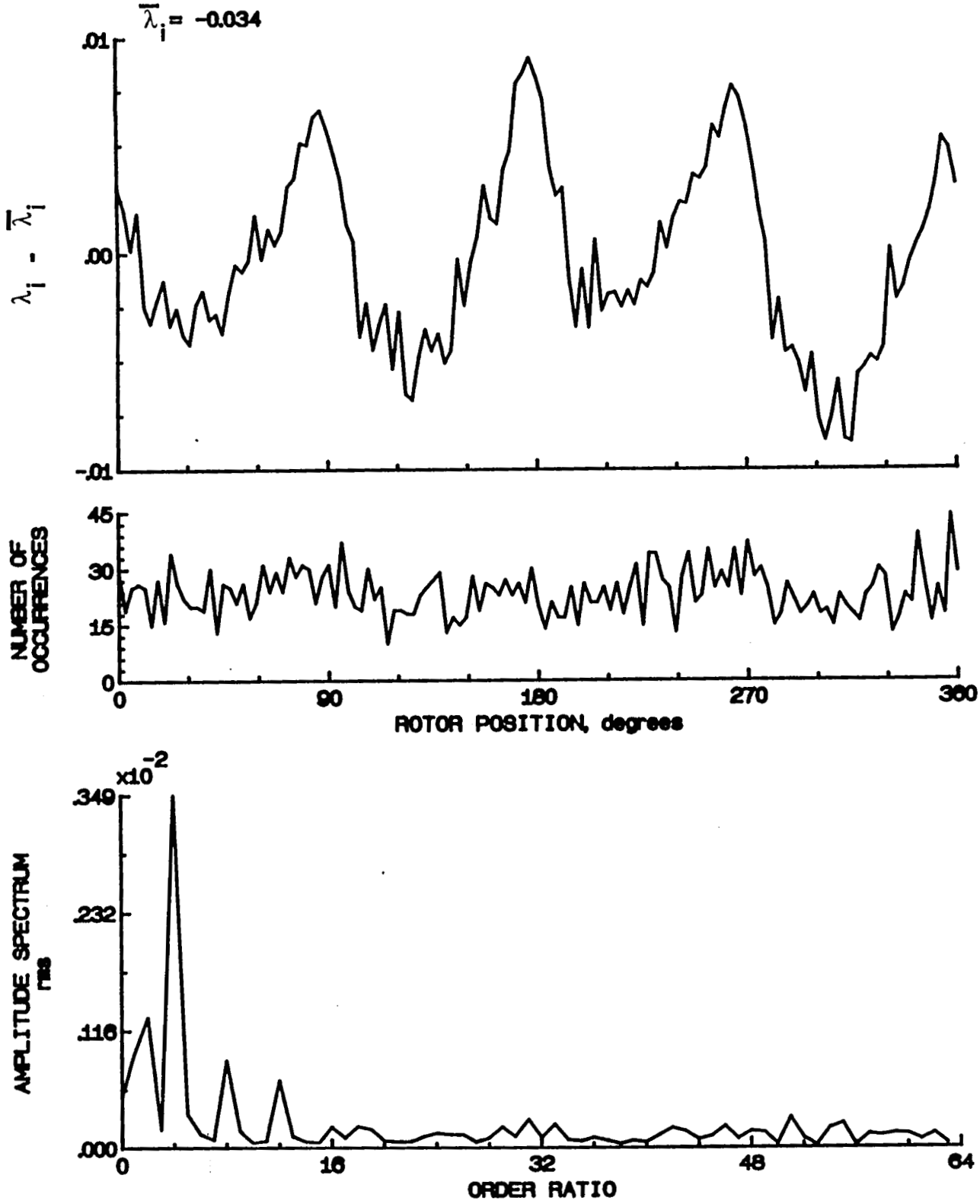


Figure 26.- Induced inflow velocity measured at 0 degrees and r/R of 1.04.



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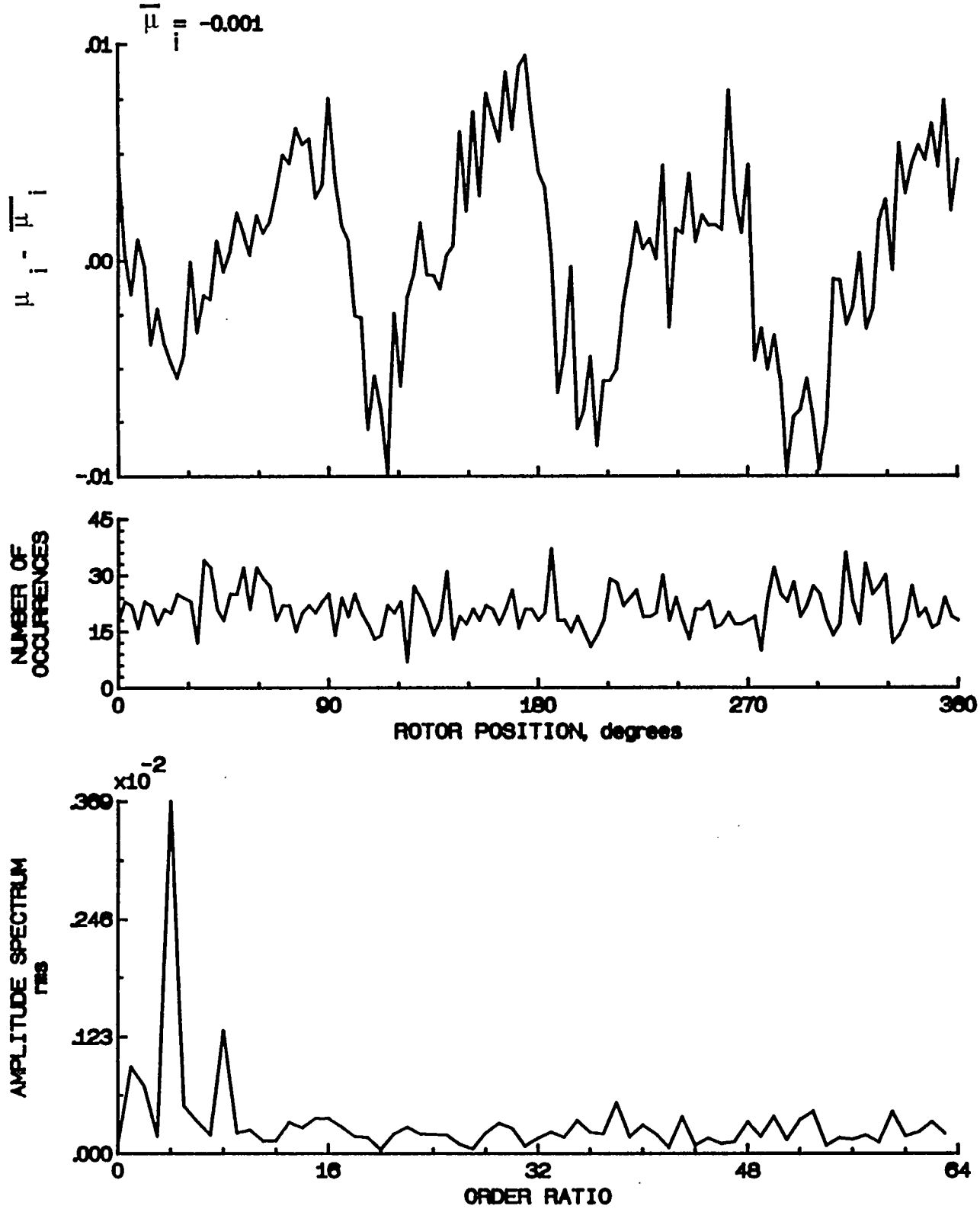
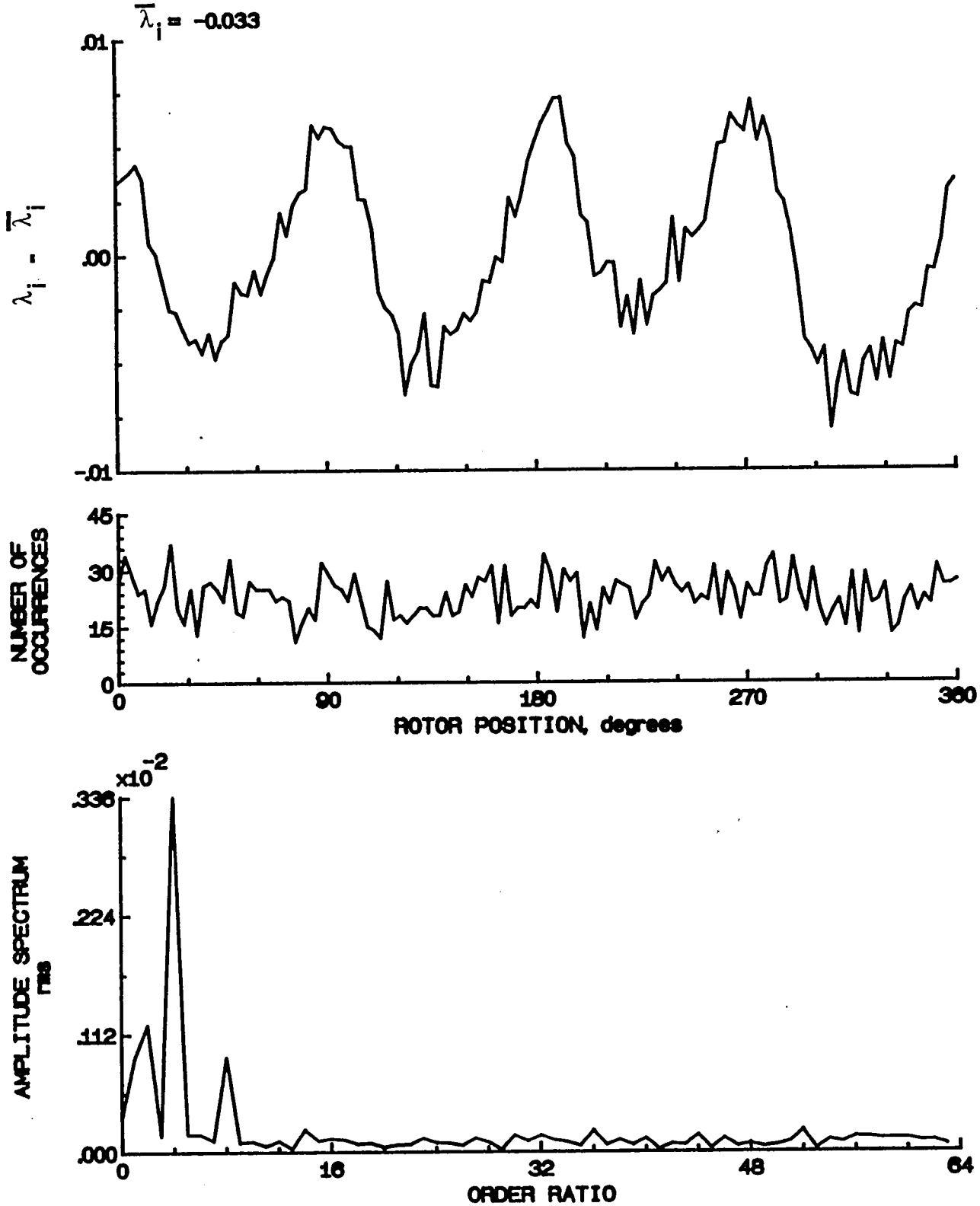


Figure 27.- Induced inflow velocity measured at 0 degrees and r/R of 1.10.



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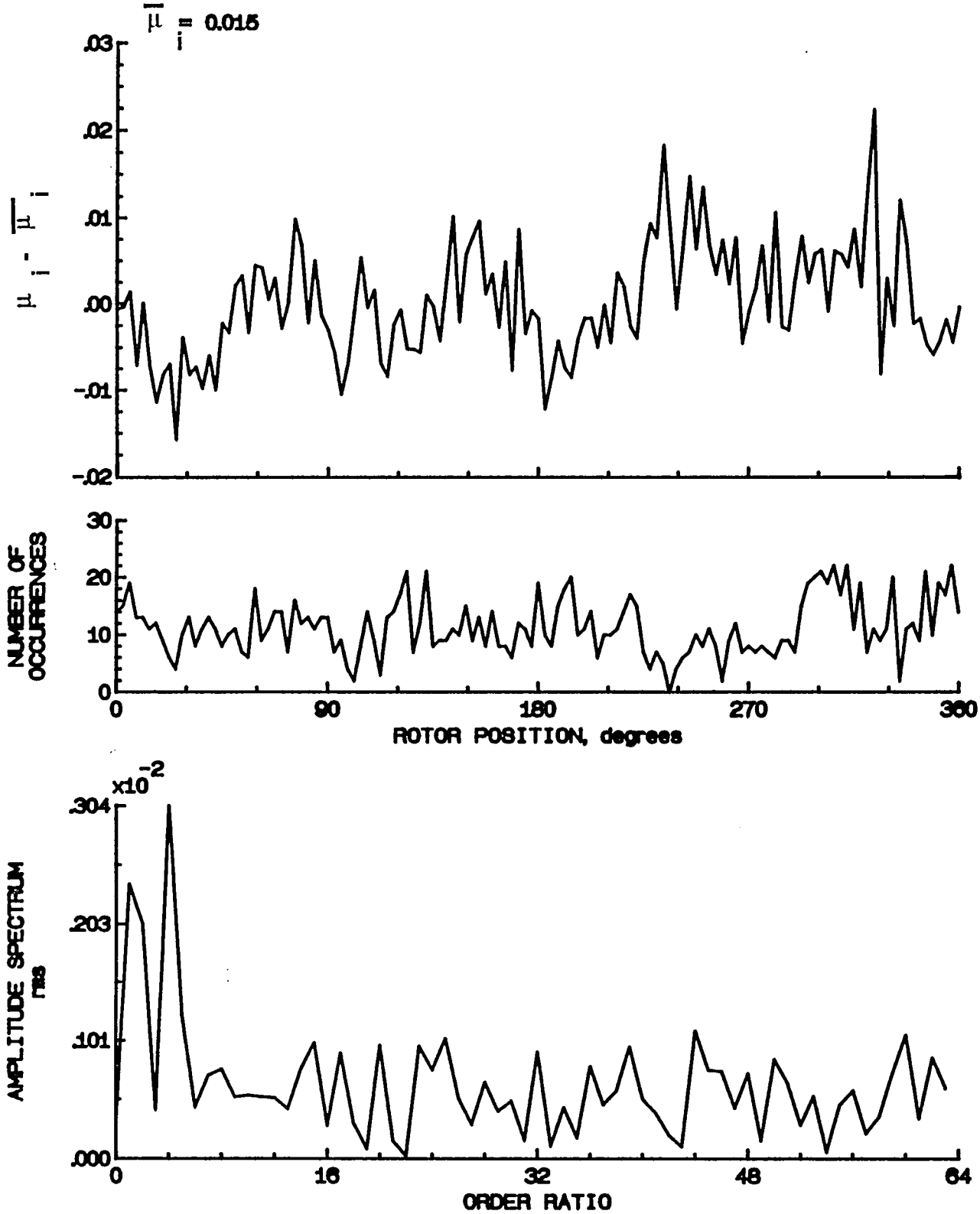
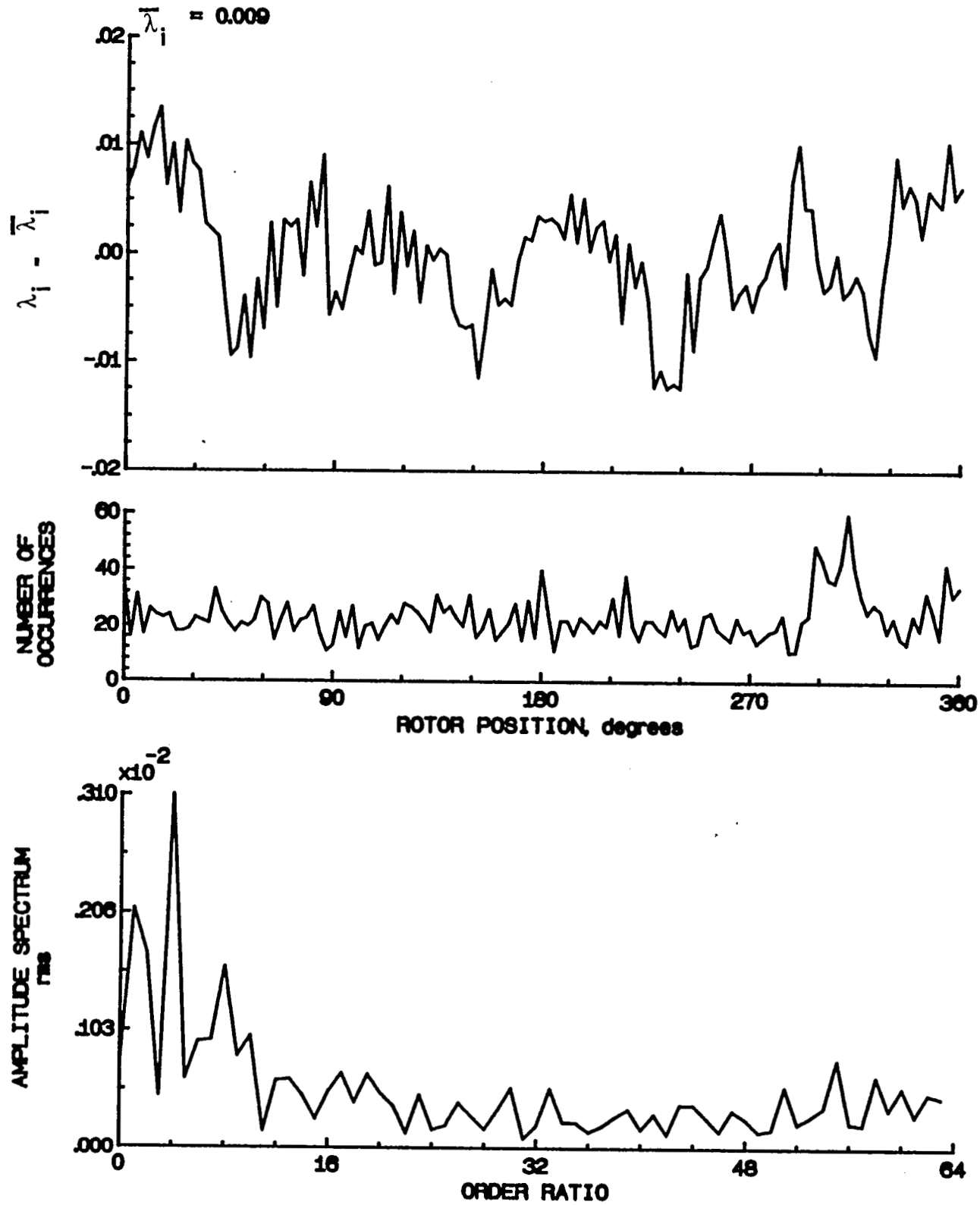


Figure 28.- Induced inflow velocity measured at 30 degrees and r/R of 0.20.



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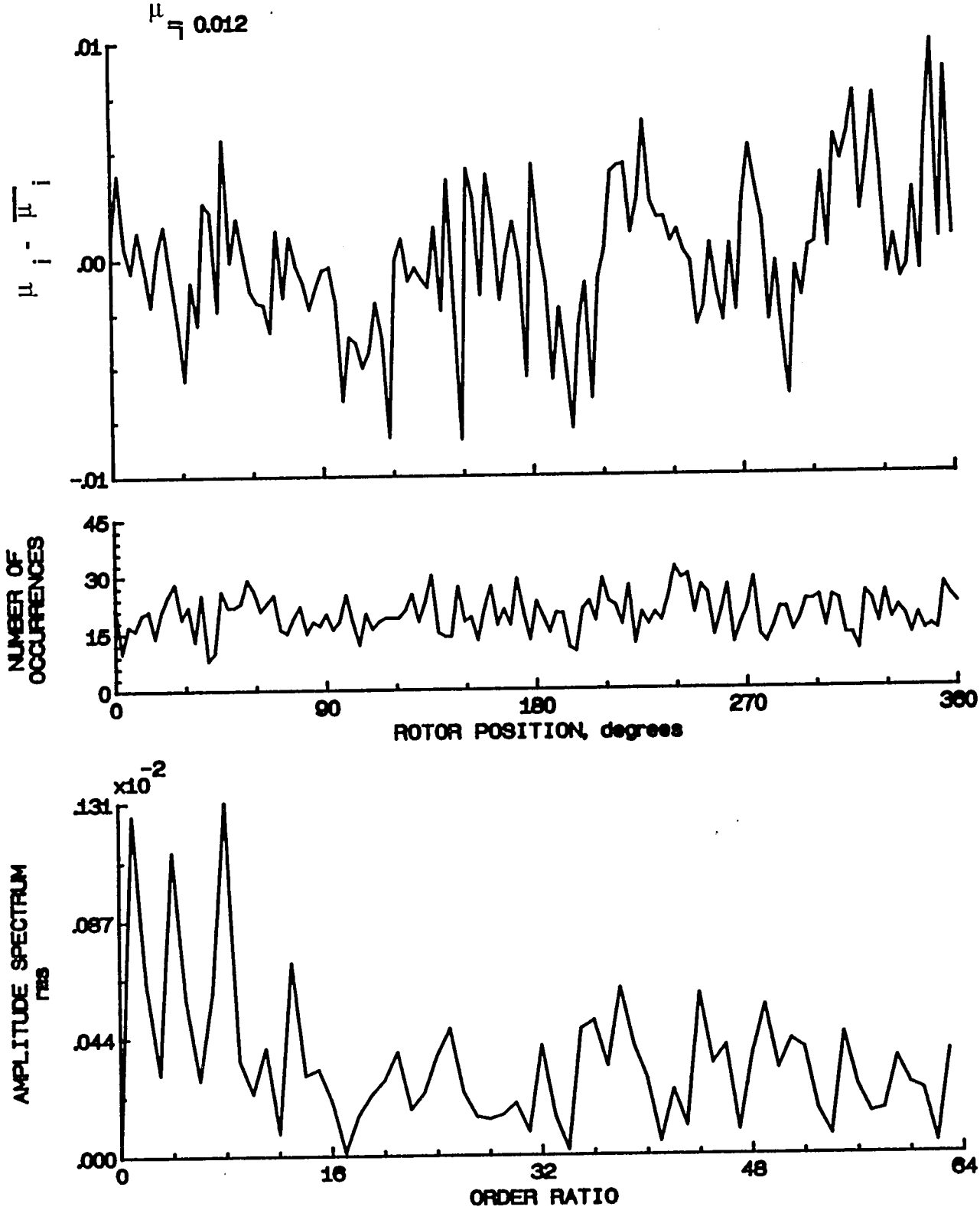
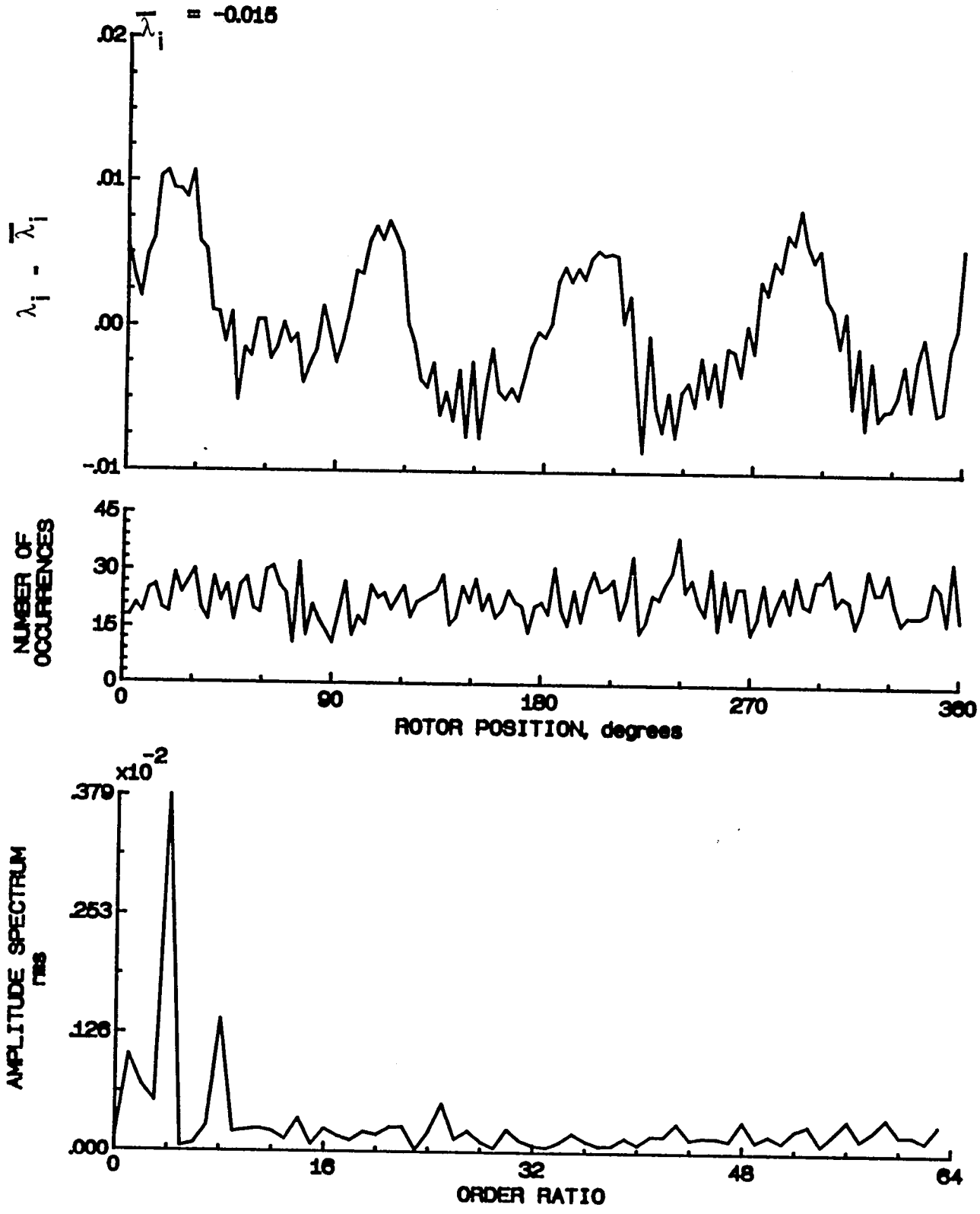


Figure 29.- Induced inflow velocity measured at 30 degrees and r/R of 0.40.



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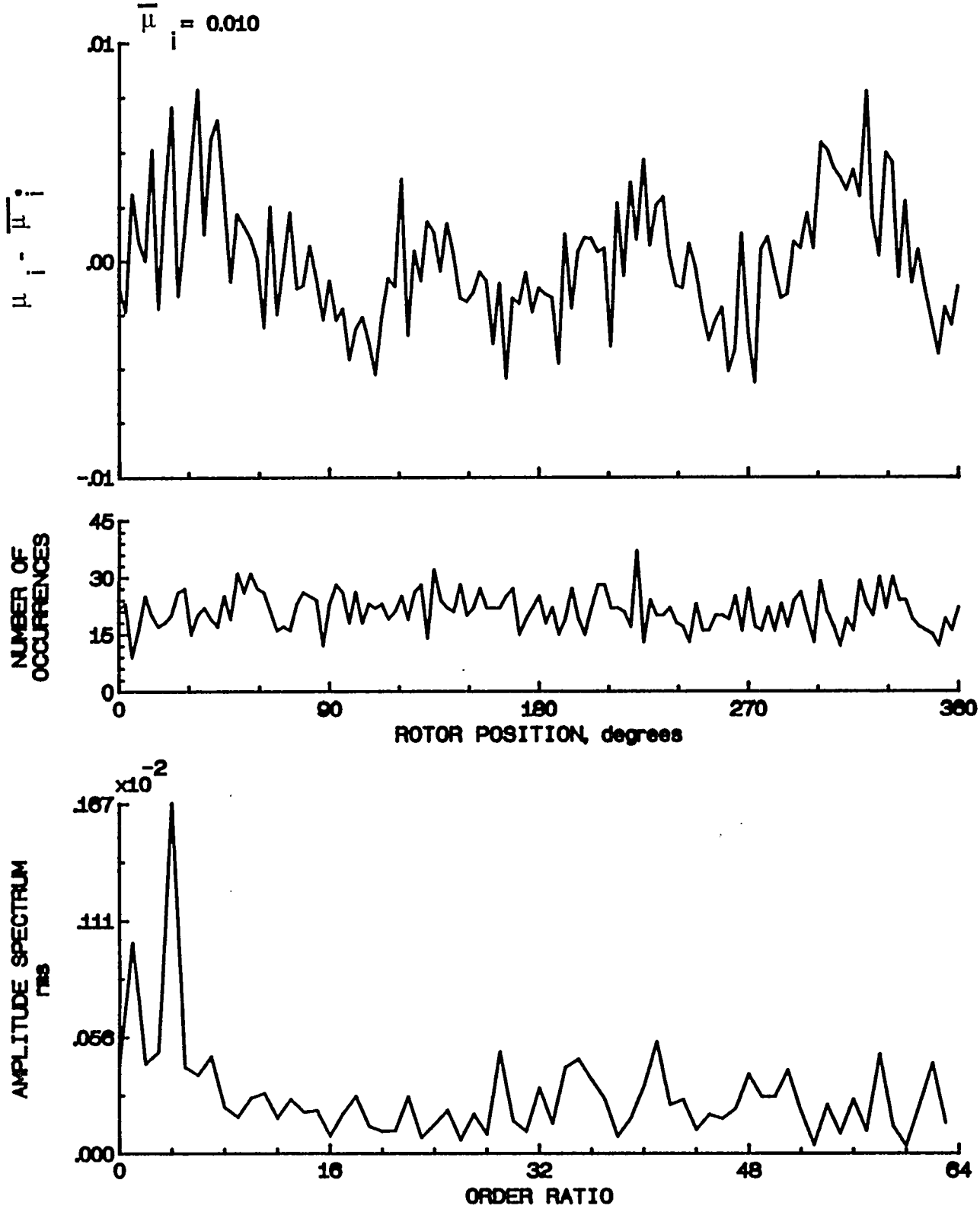
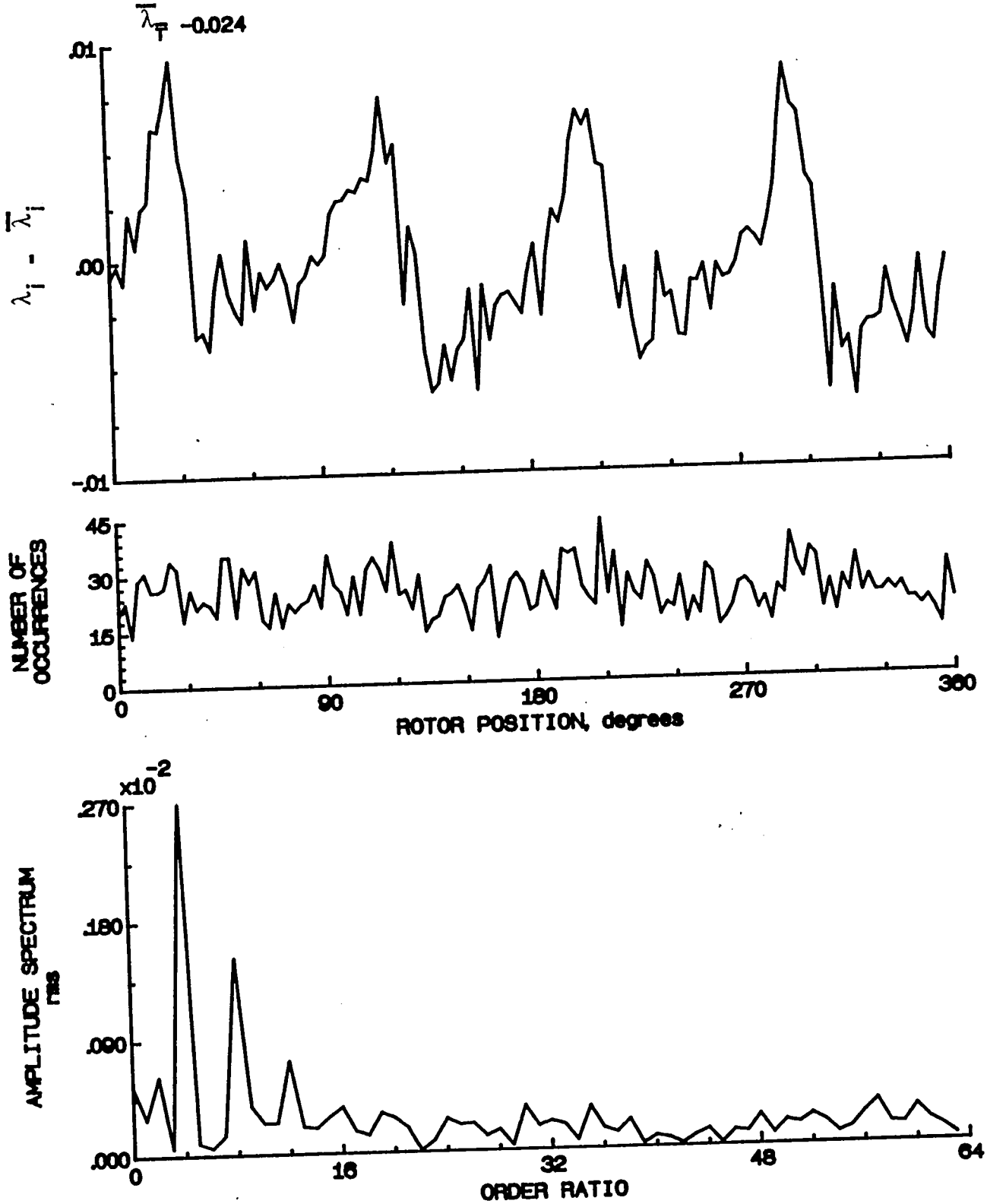


Figure 30.- Induced inflow velocity measured at 30 degrees and r/R of 0.50.



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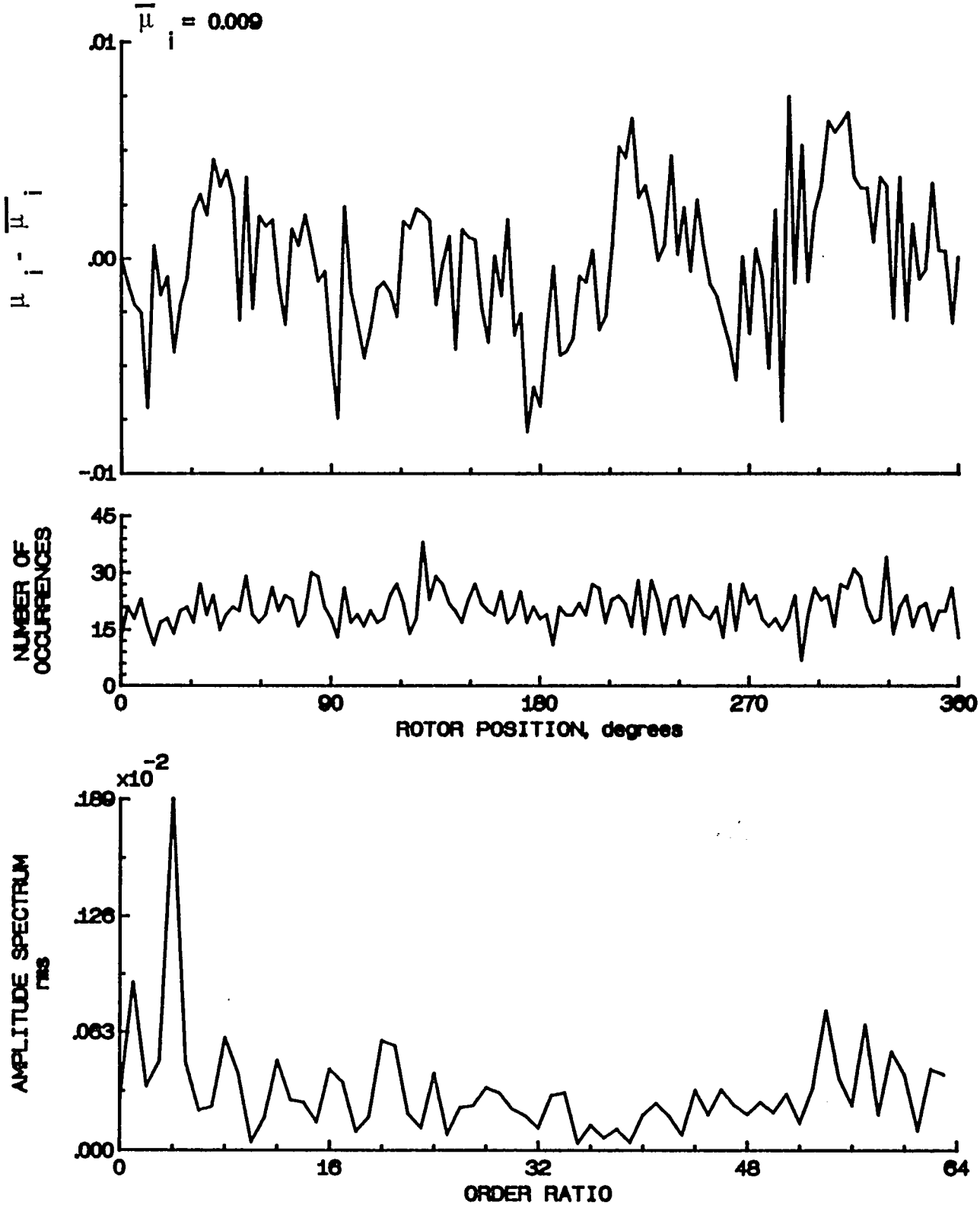
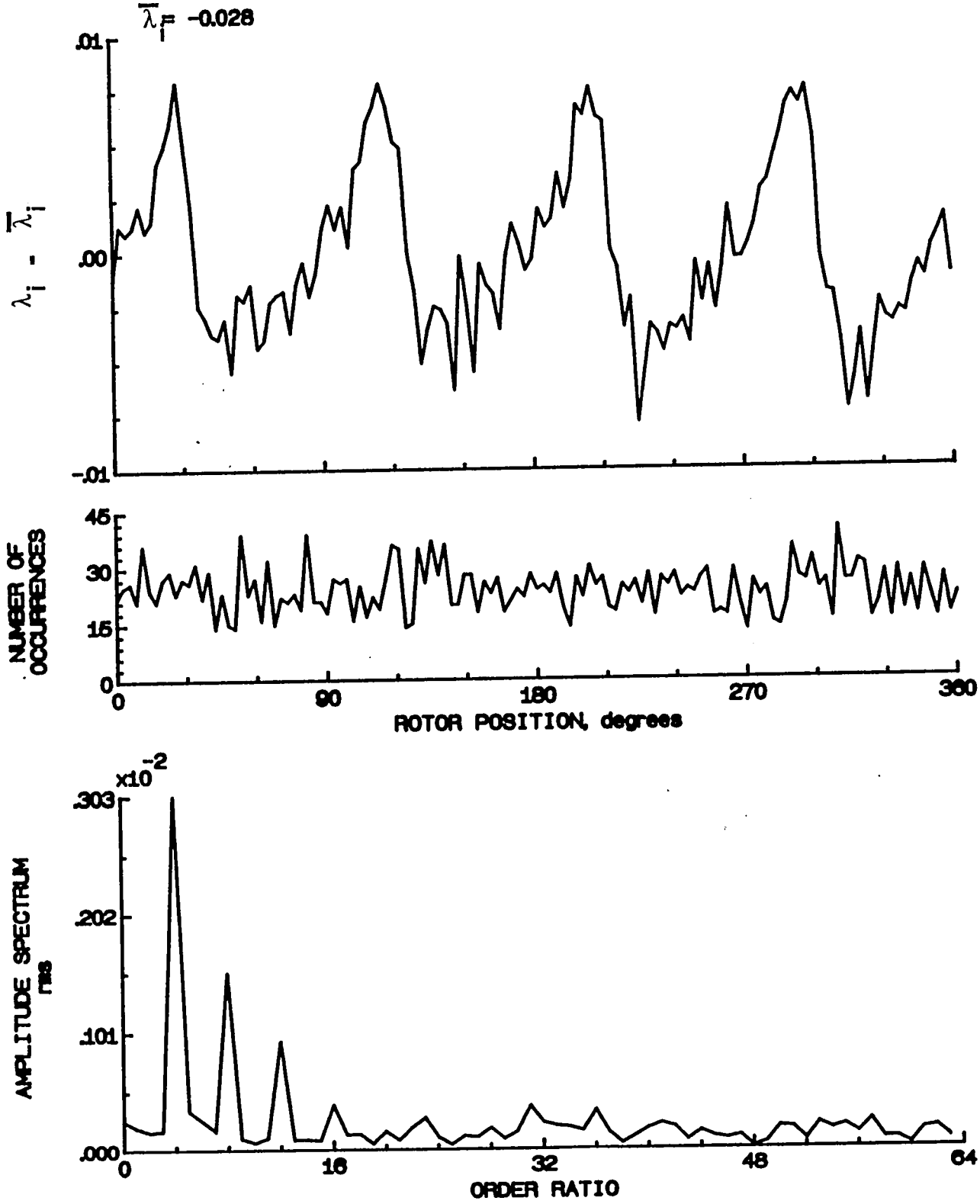


Figure 31.- Induced inflow velocity measured at 30 degrees and r/R of 0.60.



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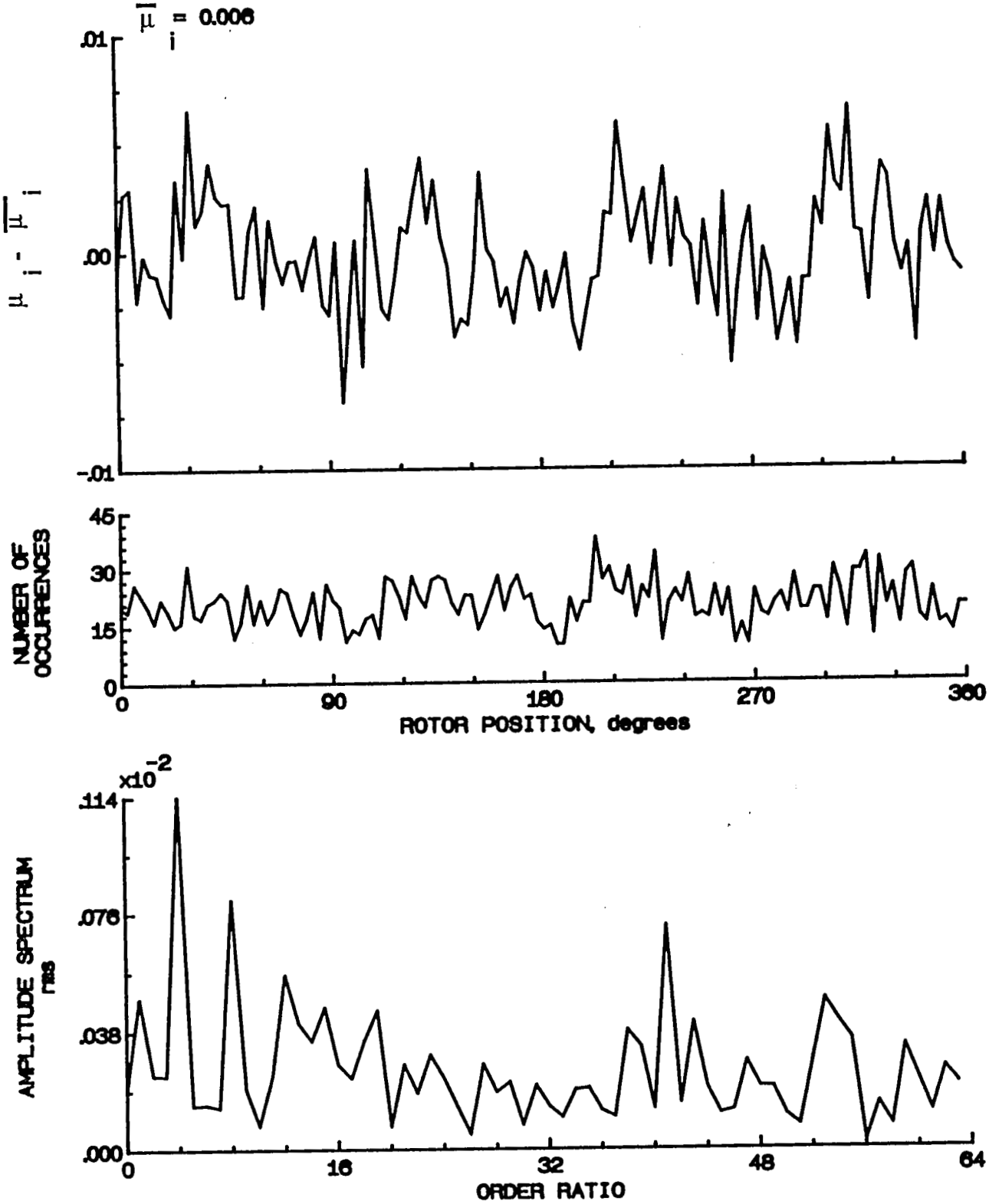
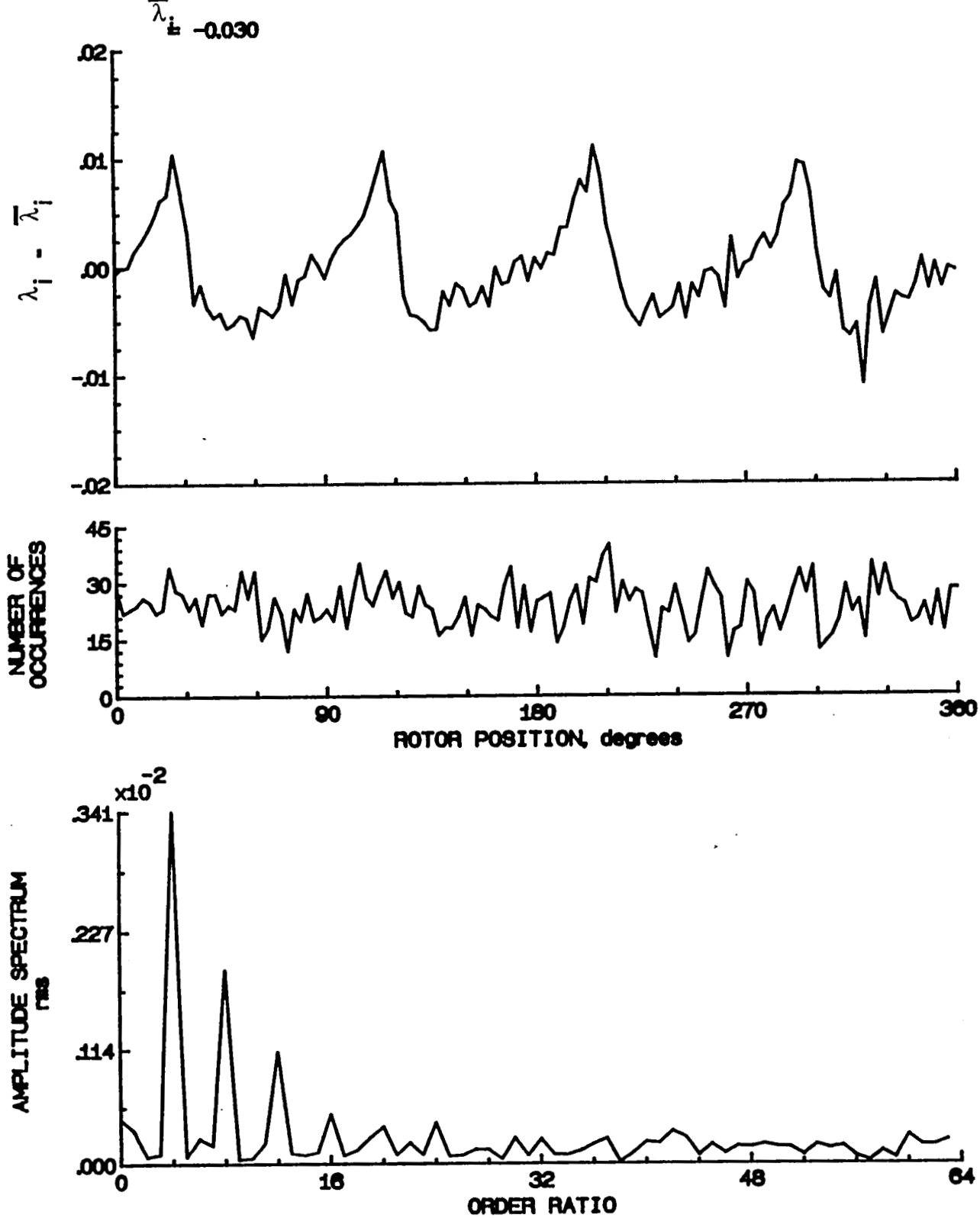


Figure 32.- Induced inflow velocity measured at 30 degrees and r/R of 0.70.



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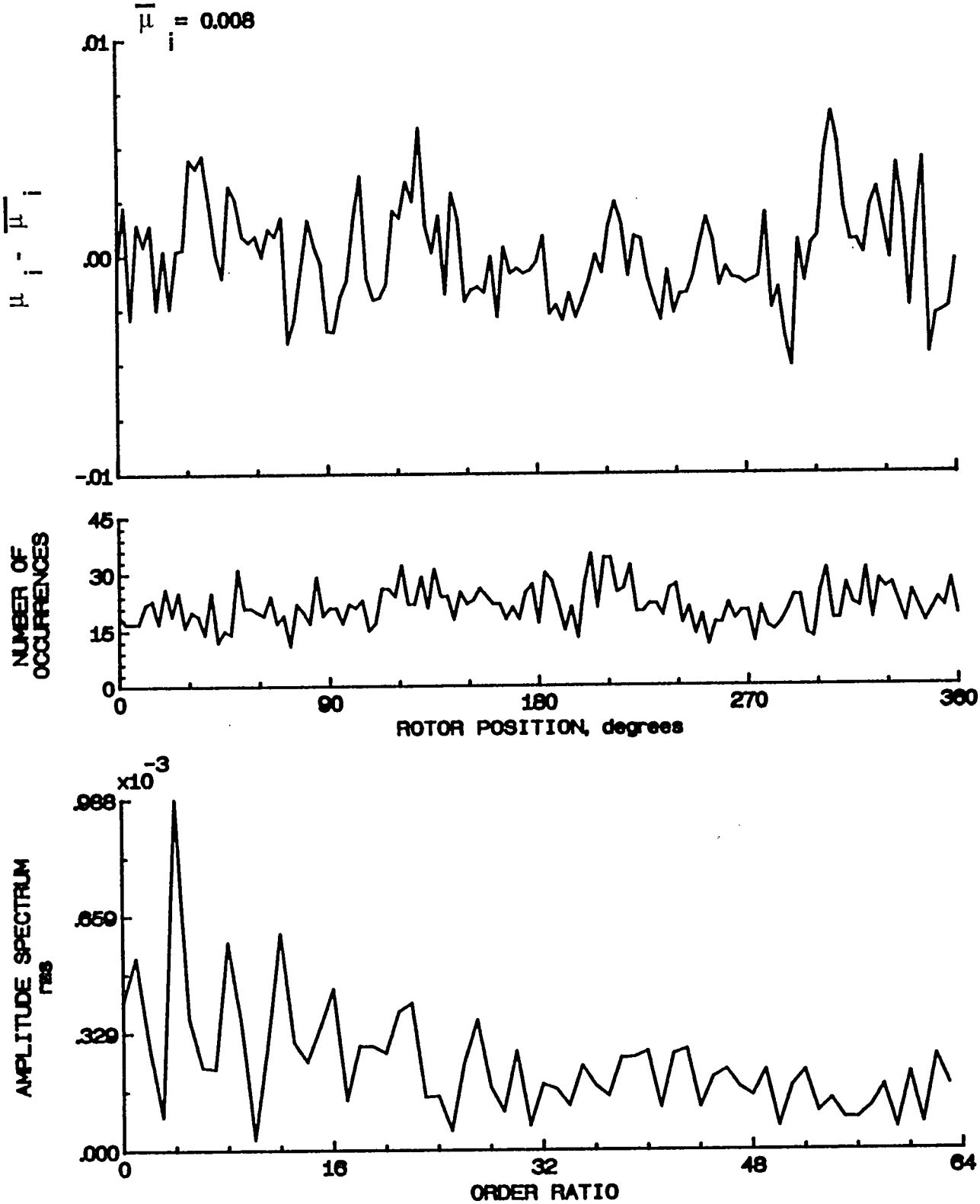
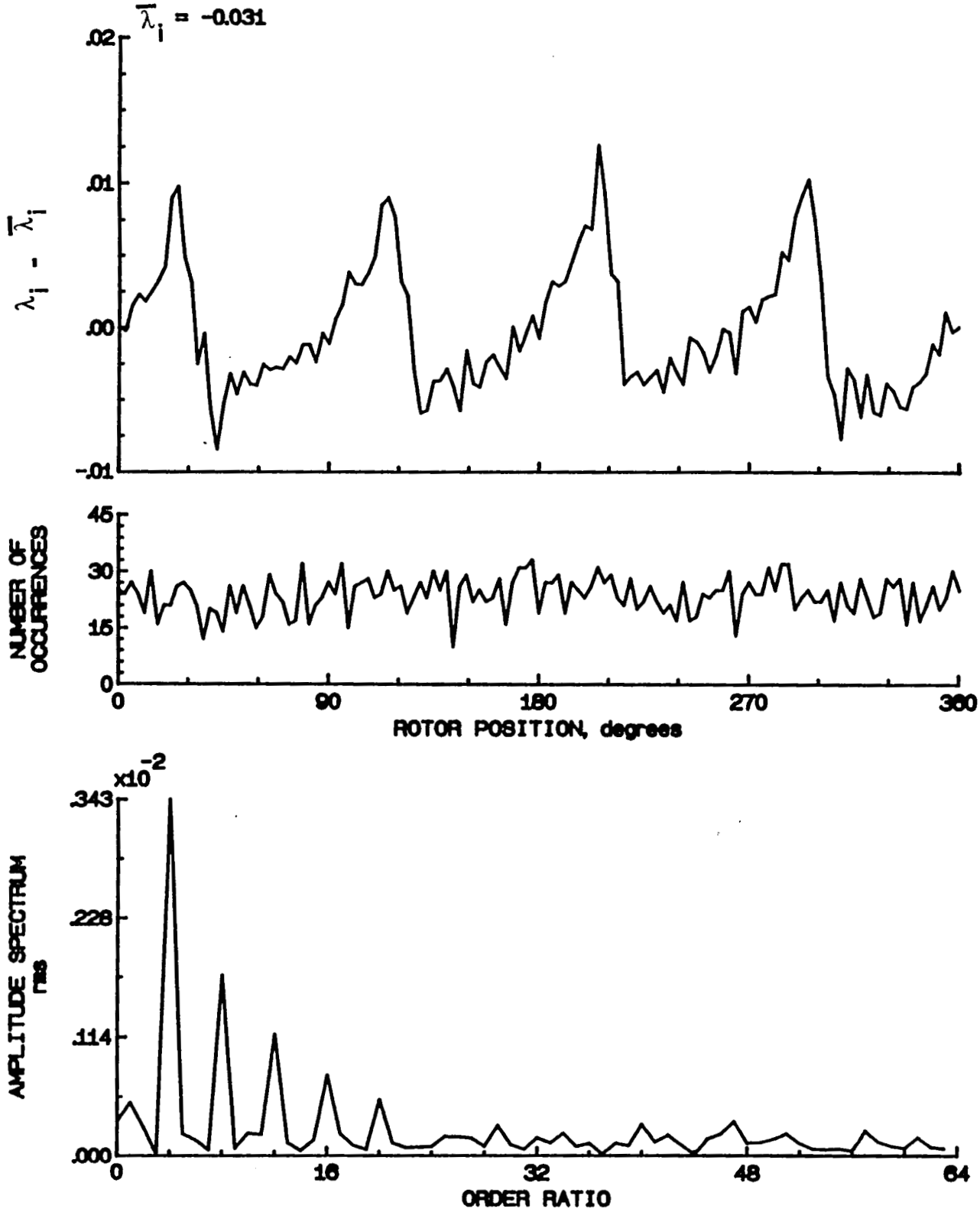


Figure 33.- Induced inflow velocity measured at 30 degrees and r/R of 0.74.



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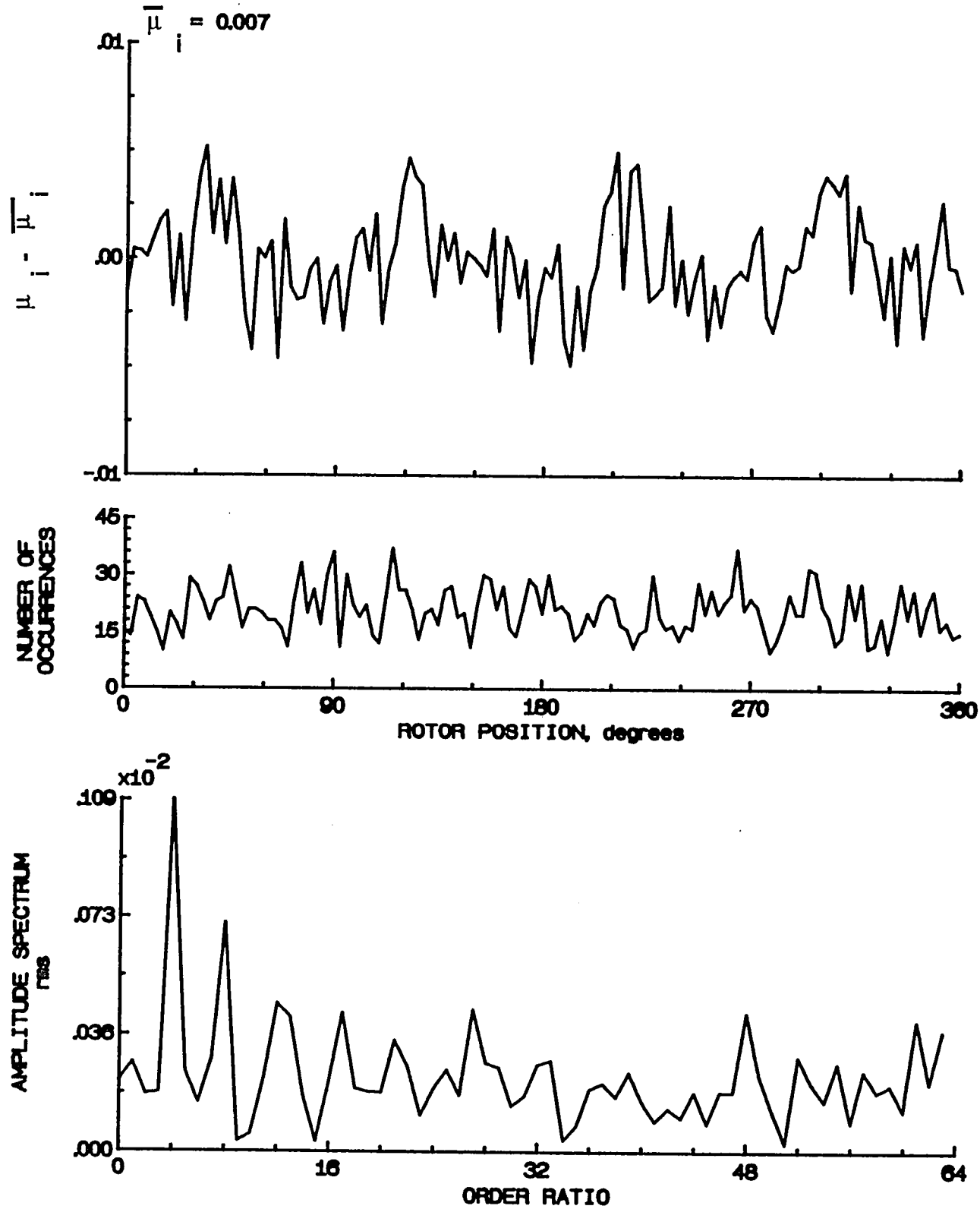
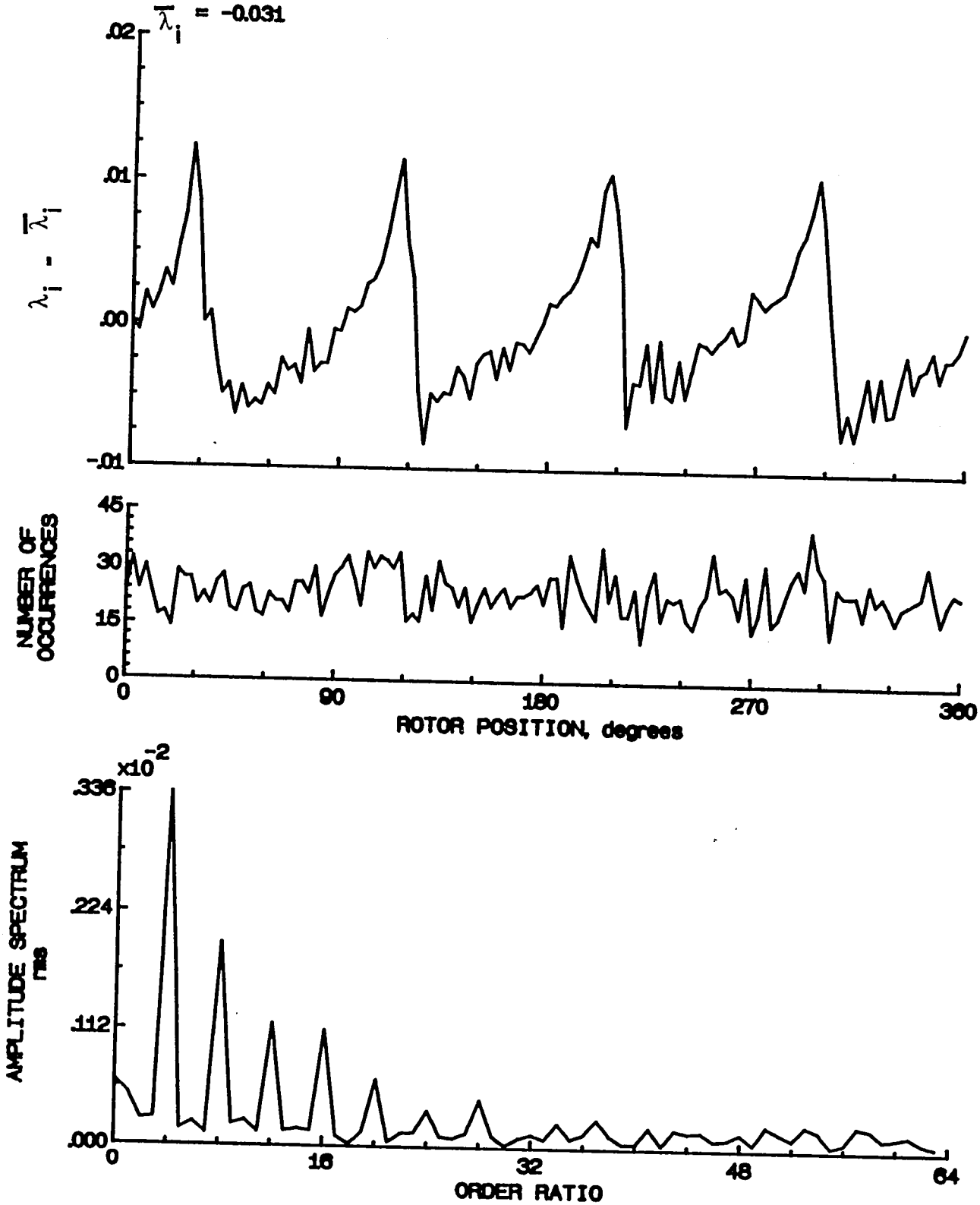


Figure 34.- Induced inflow velocity measured at 30 degrees and r/R of 0.78.



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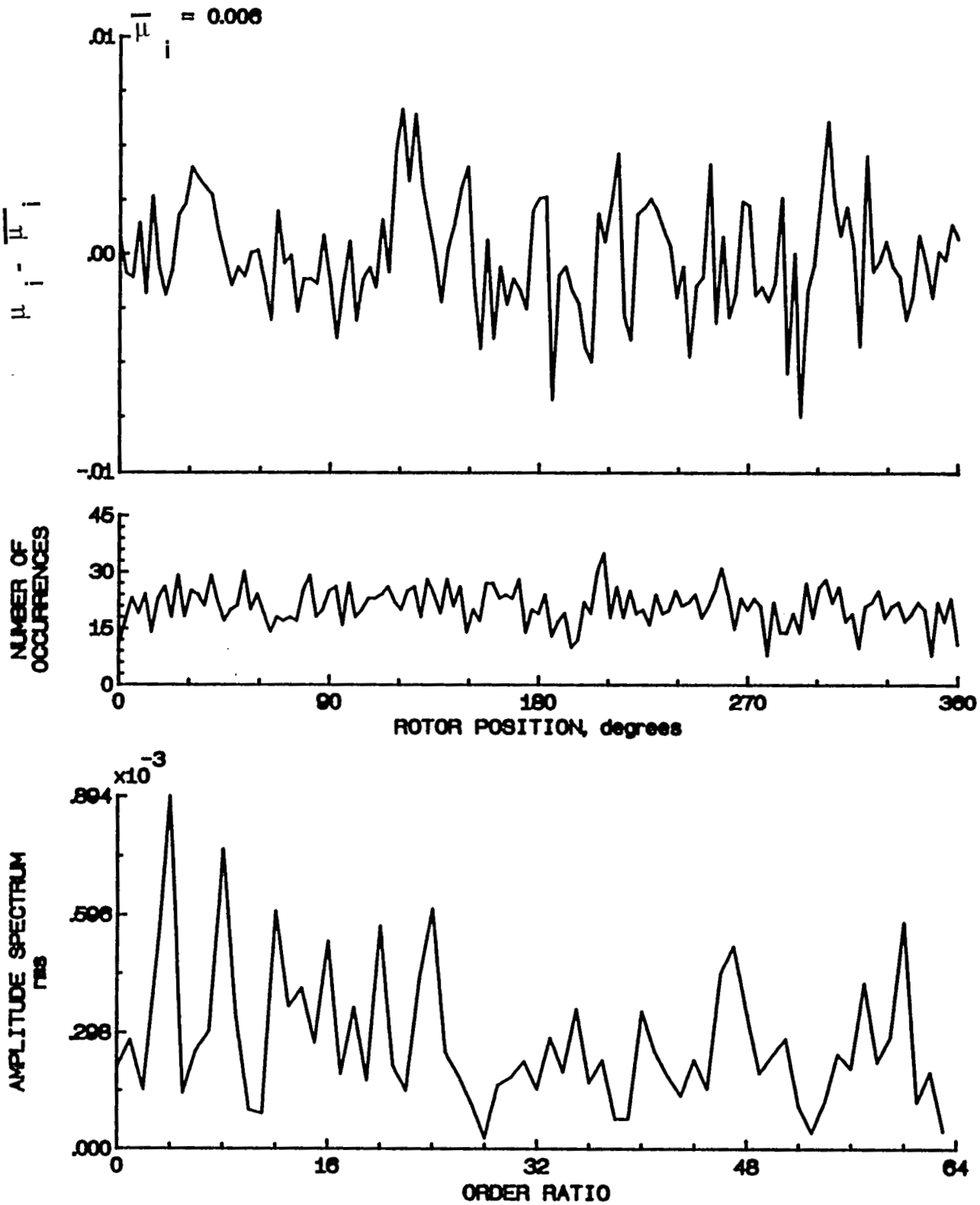
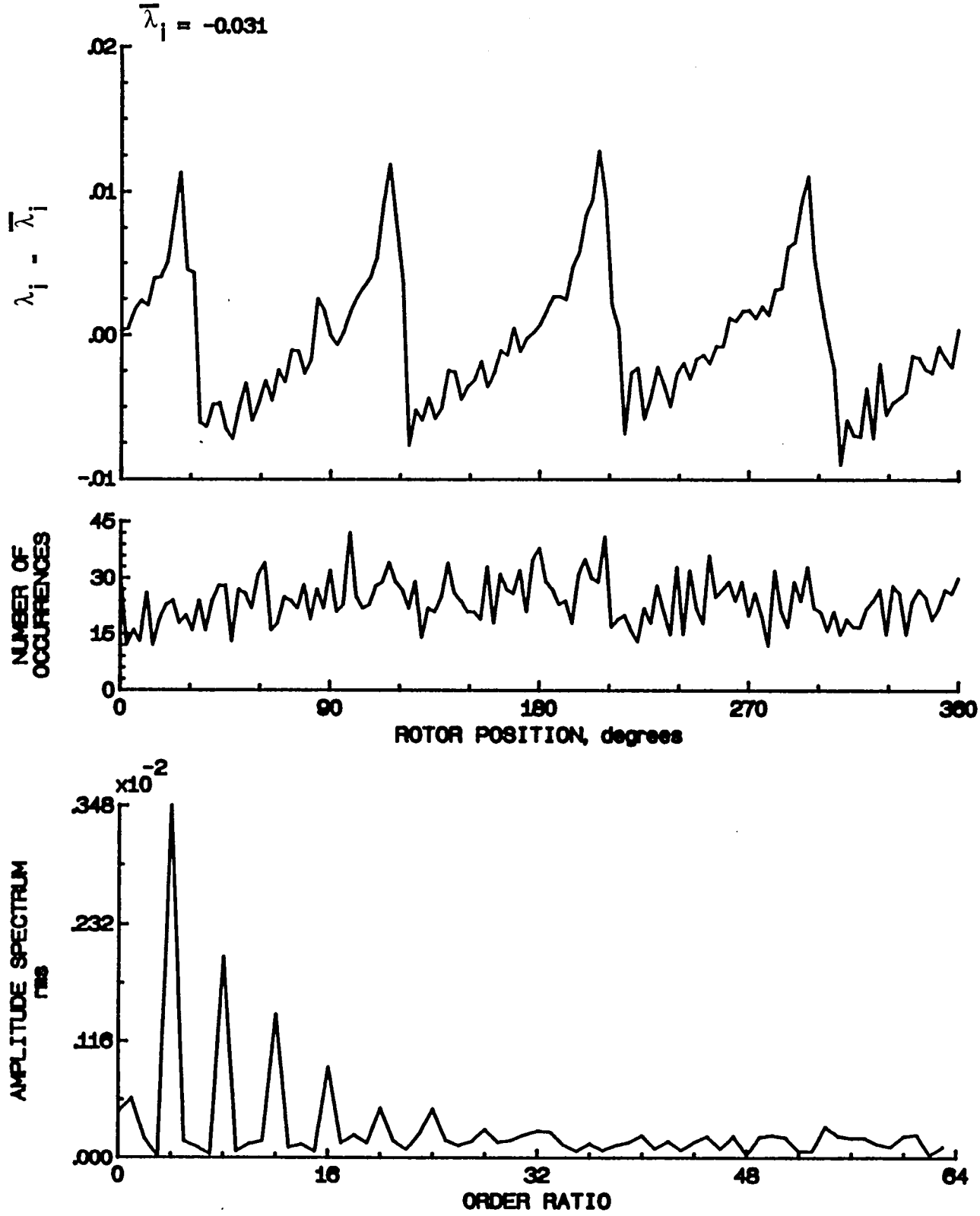


Figure 35.- Induced inflow velocity measured at 30 degrees and r/R of 0.82.



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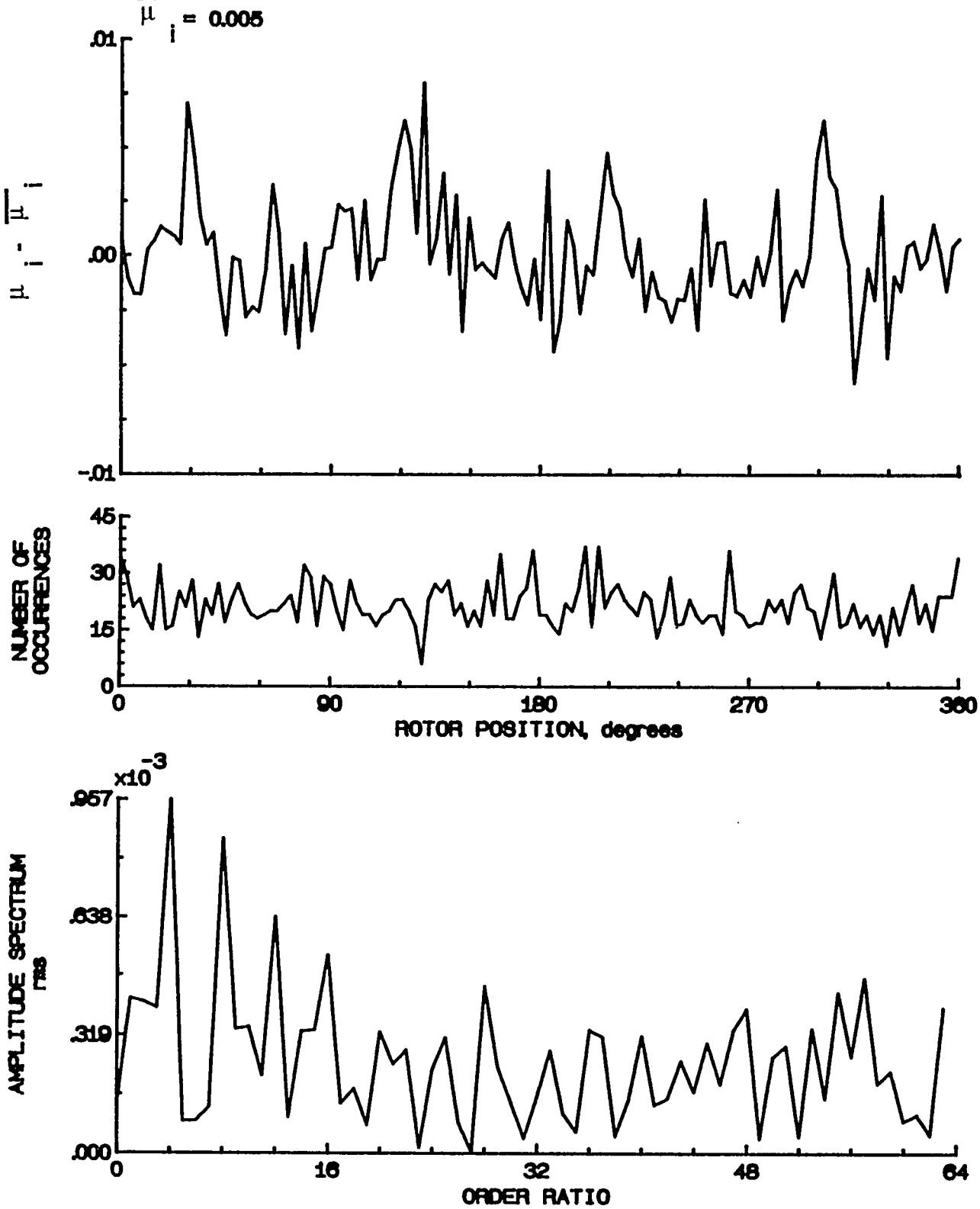
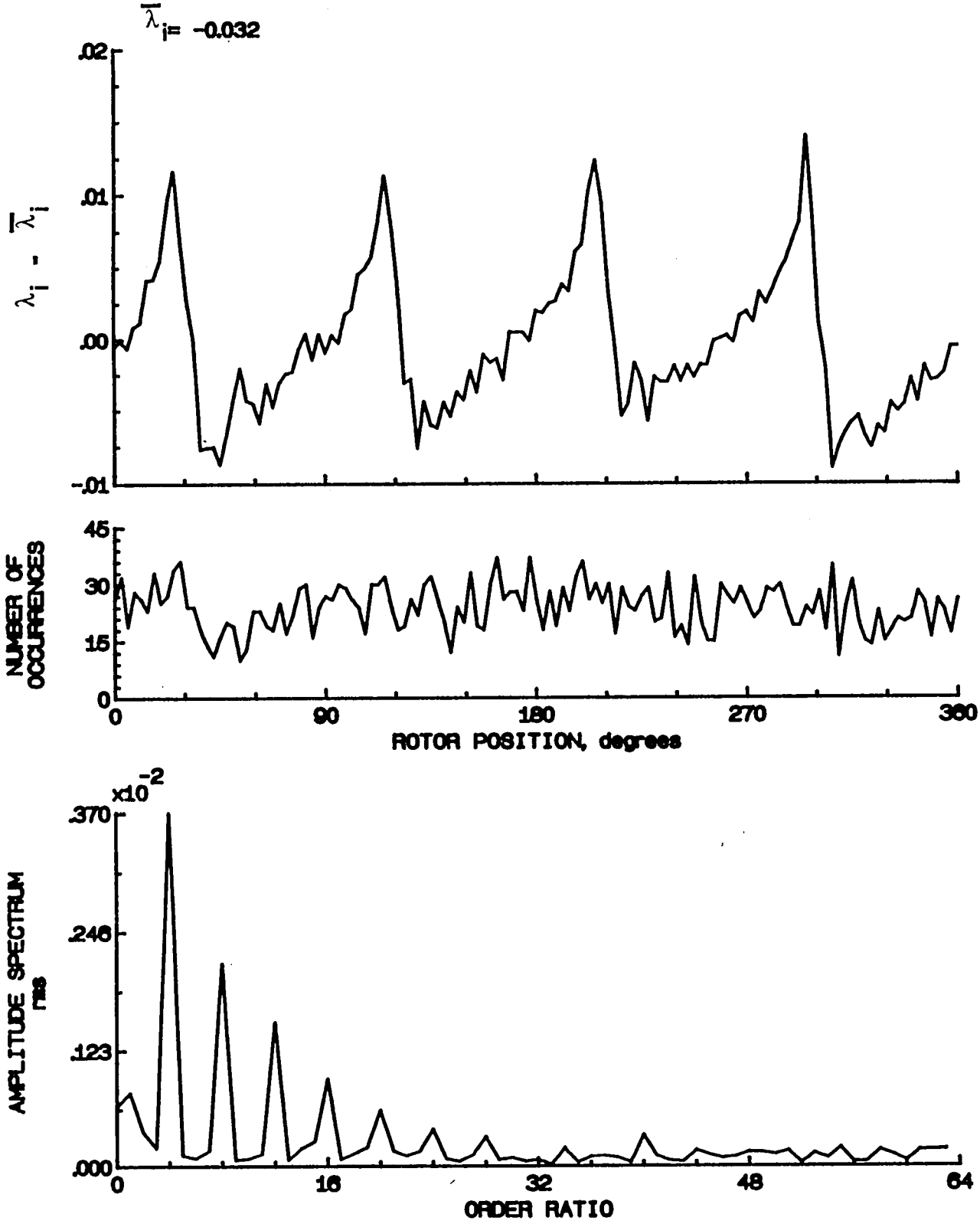


Figure 38.- Induced inflow velocity measured at 30 degrees and r/R of 0.86.



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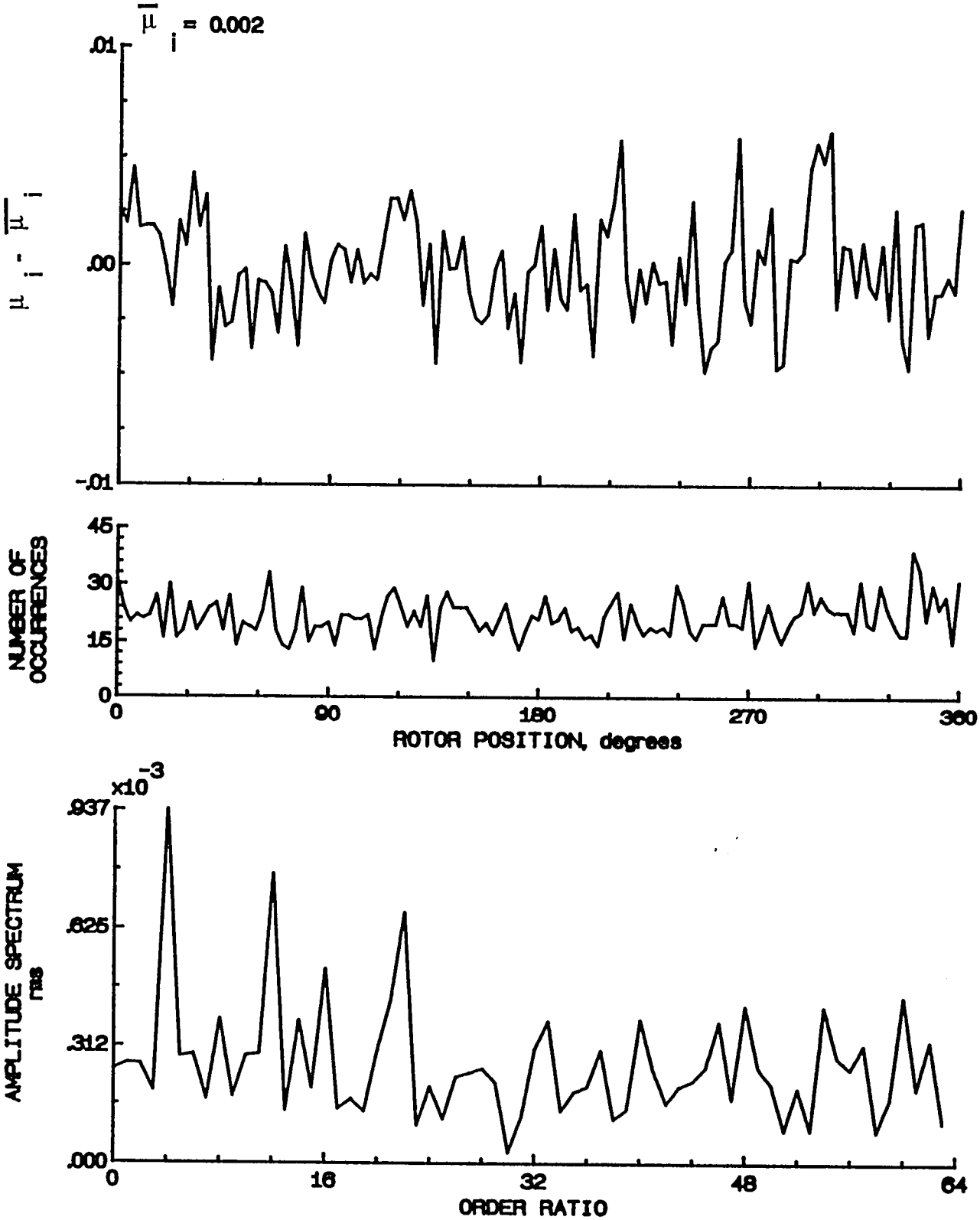
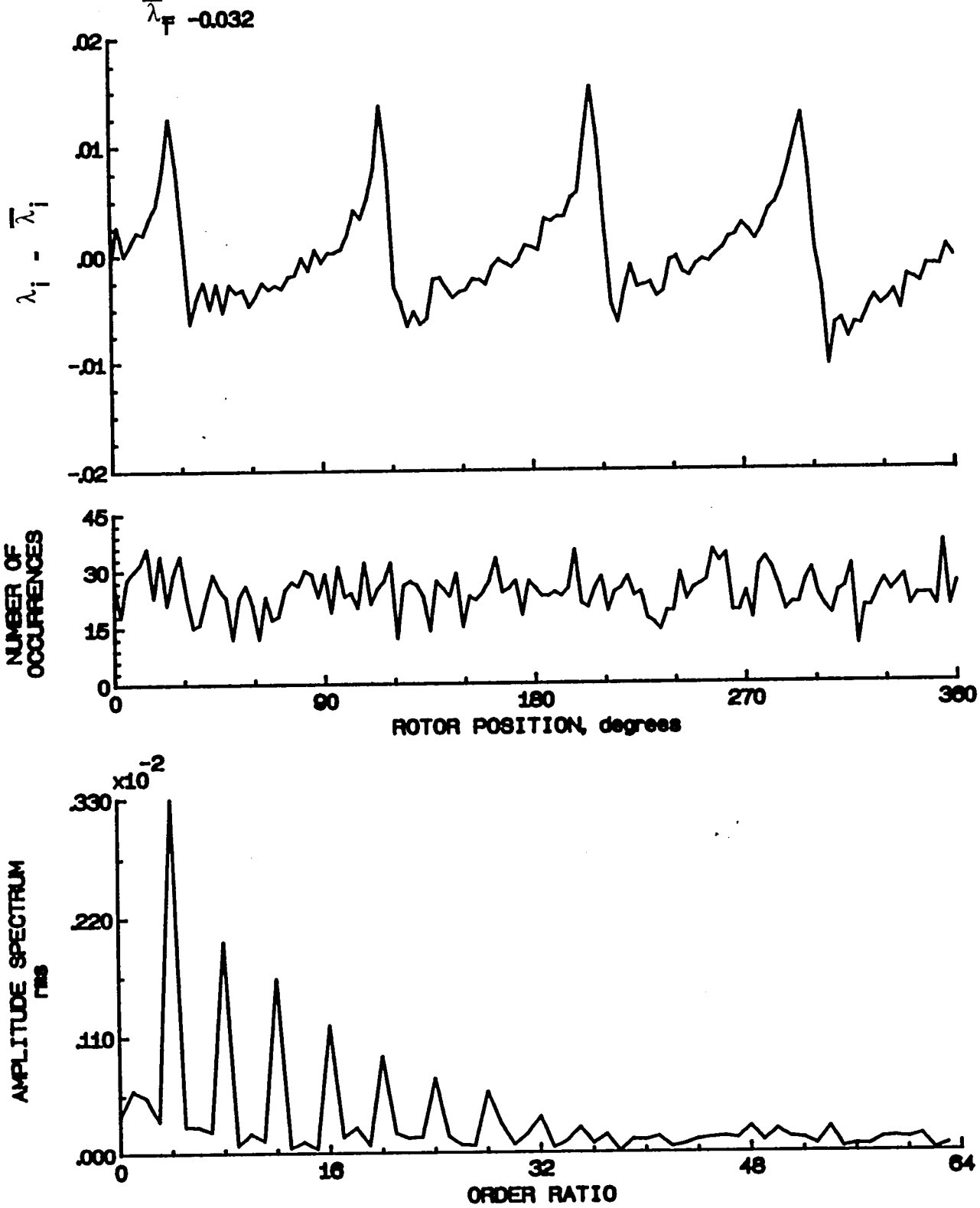


Figure 37.- Induced inflow velocity measured at 30 degrees and r/R of 0.90.



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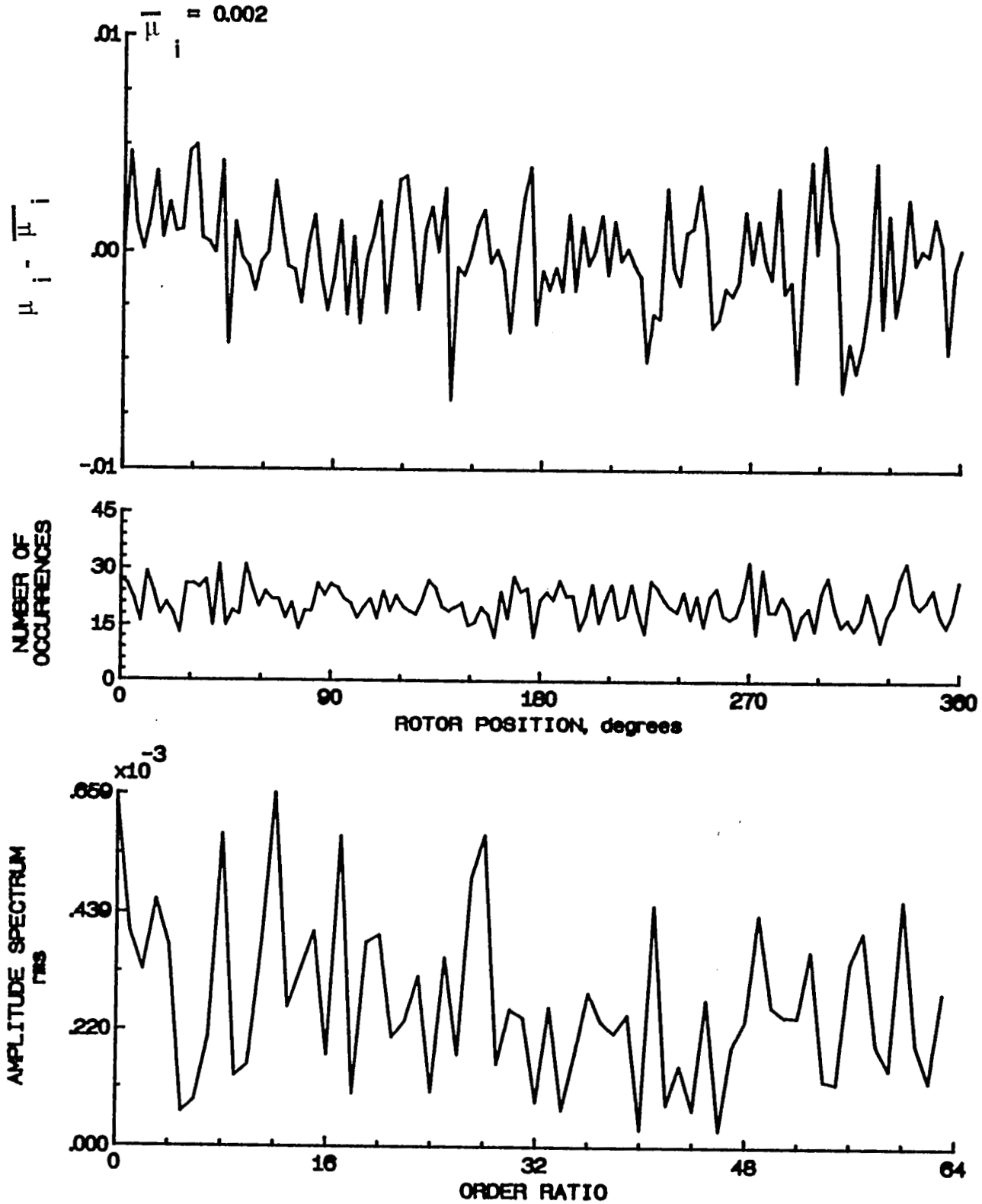
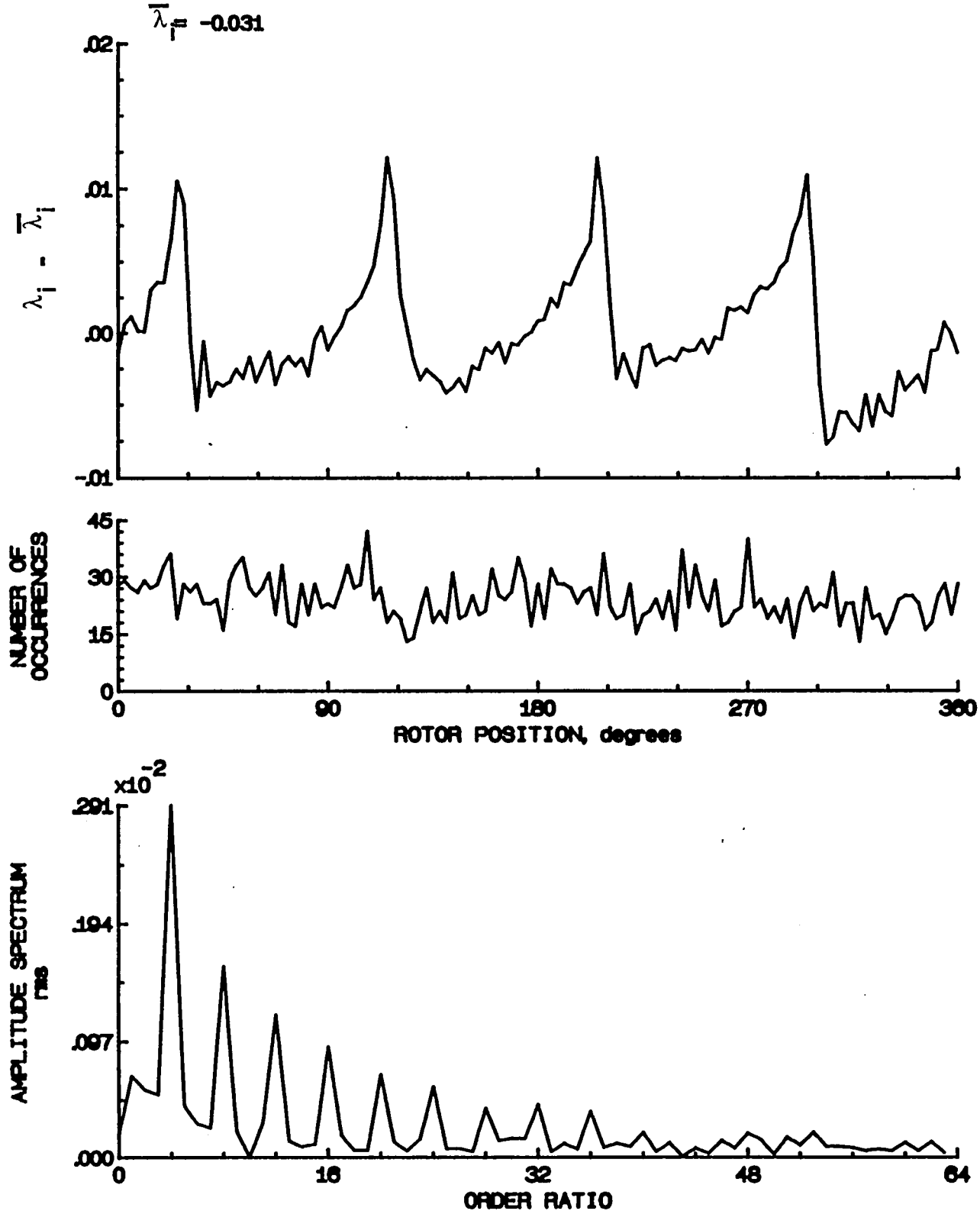


Figure 38.- Induced inflov velocity measured at 30 degrees and r/R of 0.94.



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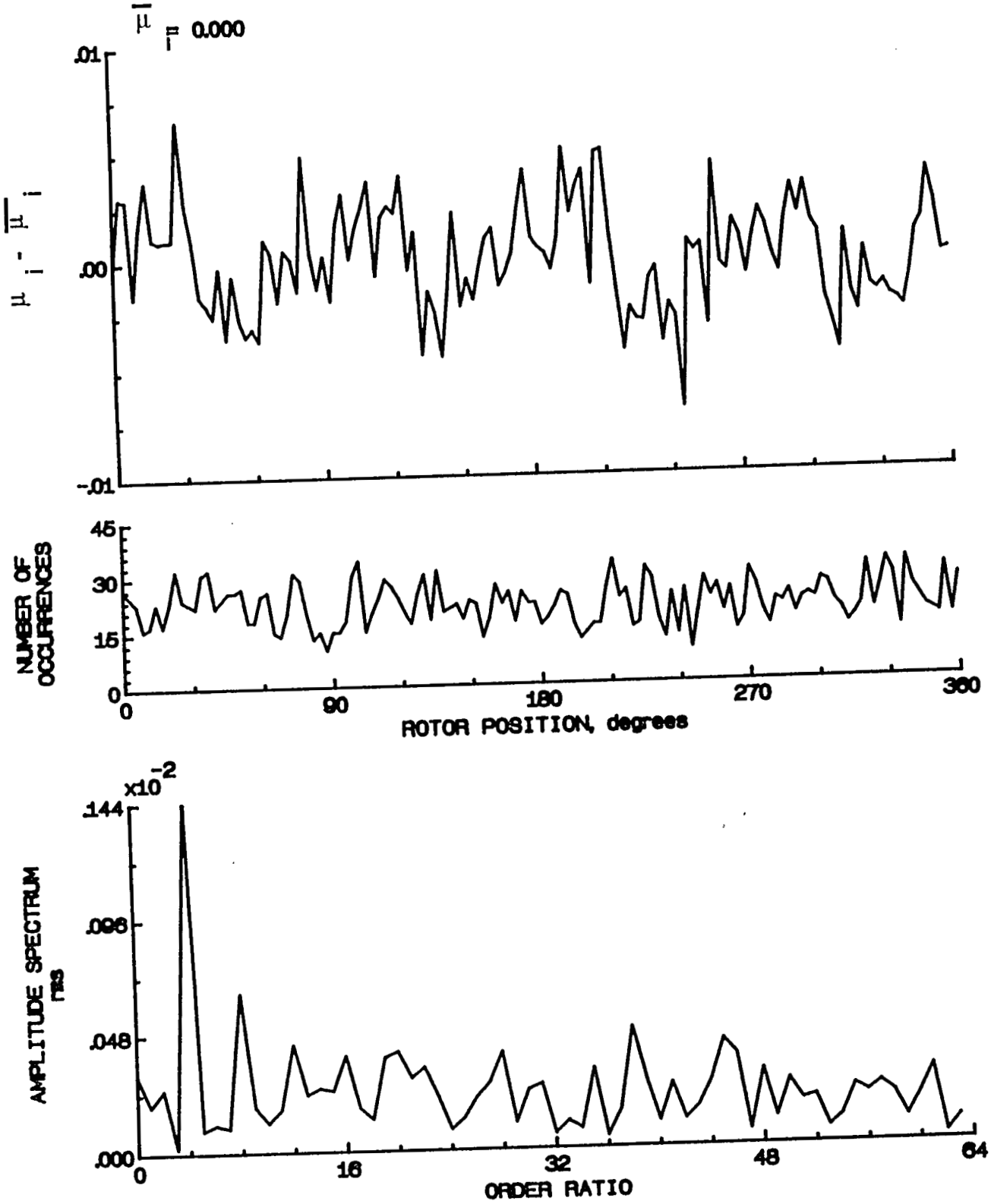
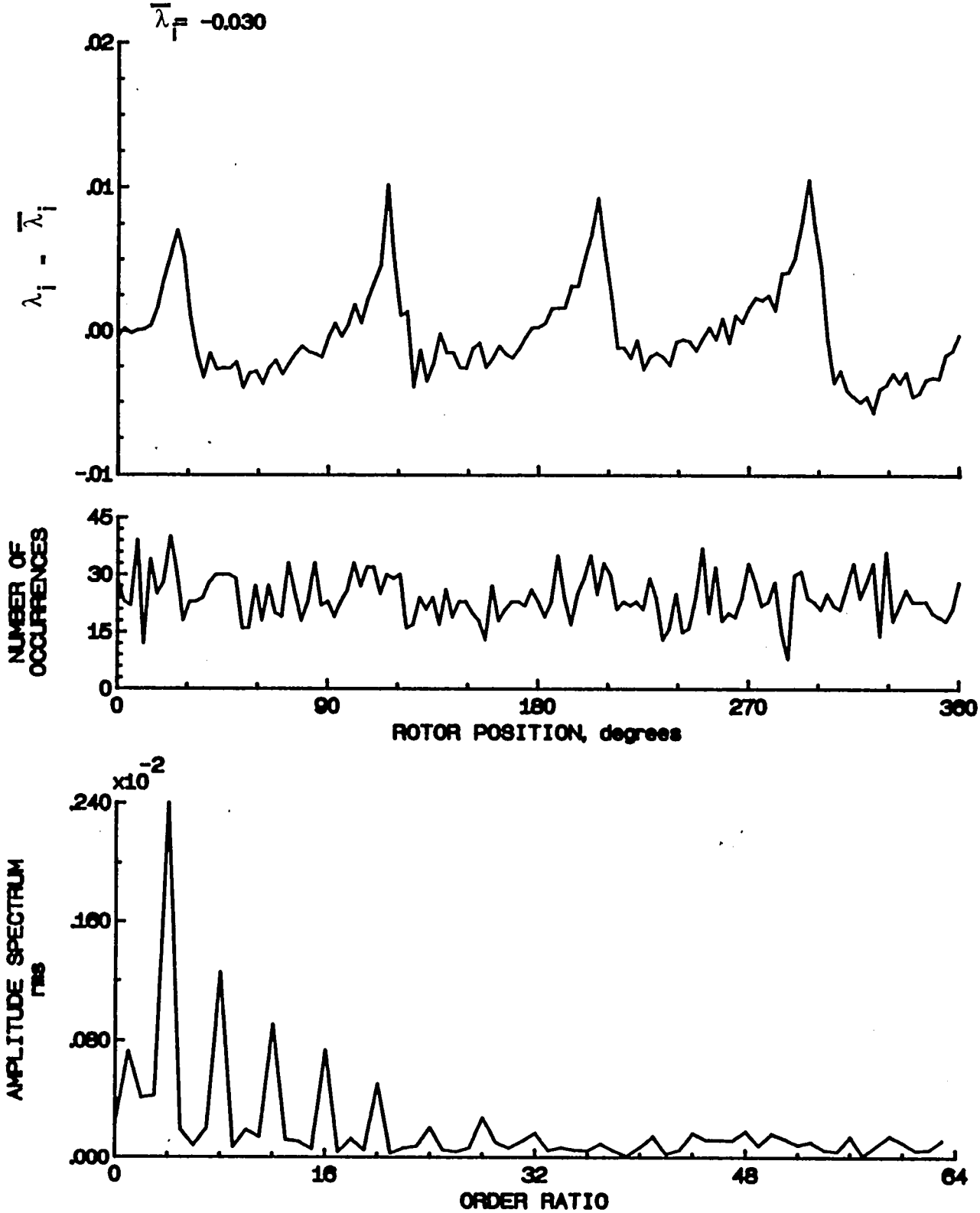


Figure 39.- Induced inflow velocity measured at 30 degrees and r/R of 0.98.



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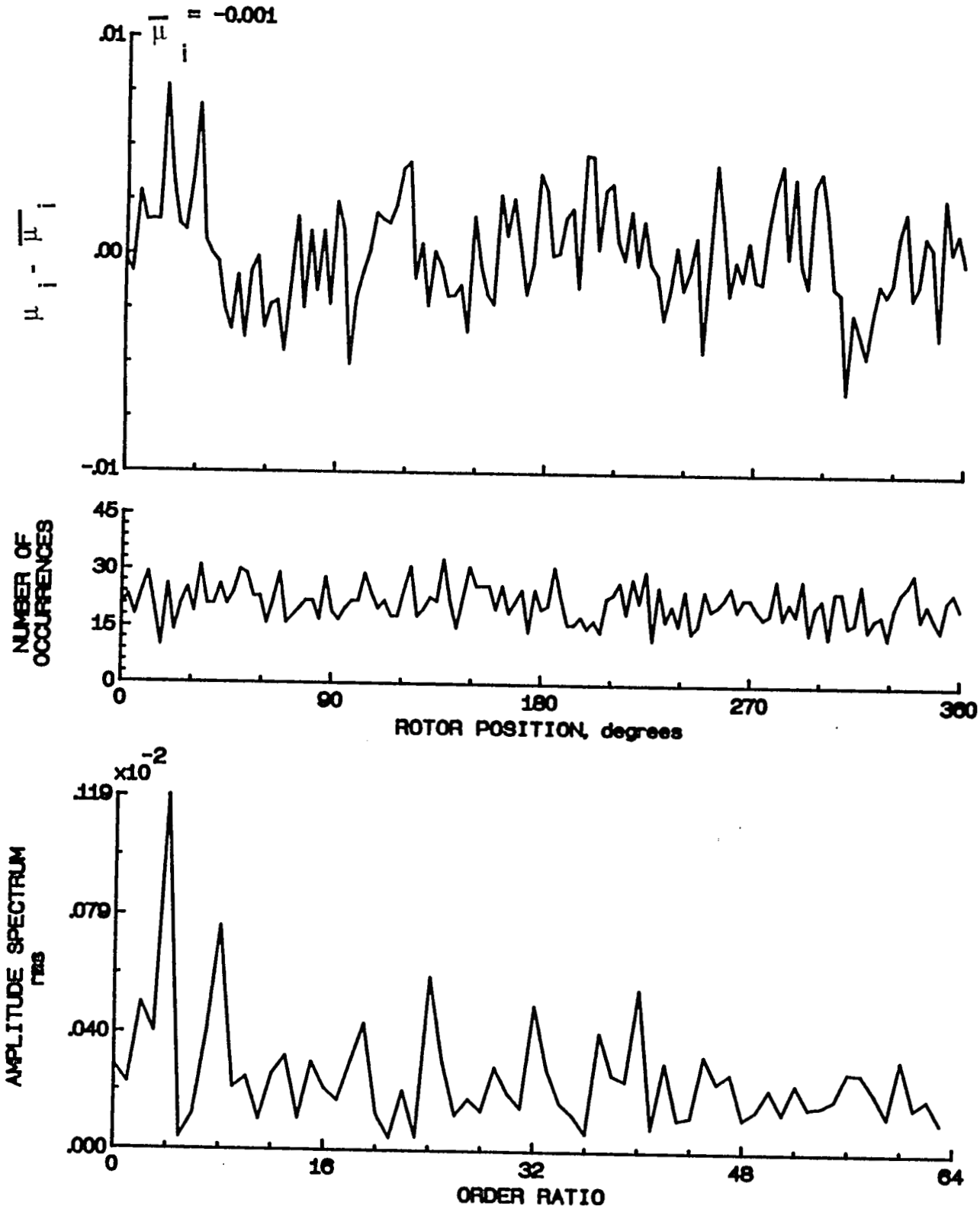
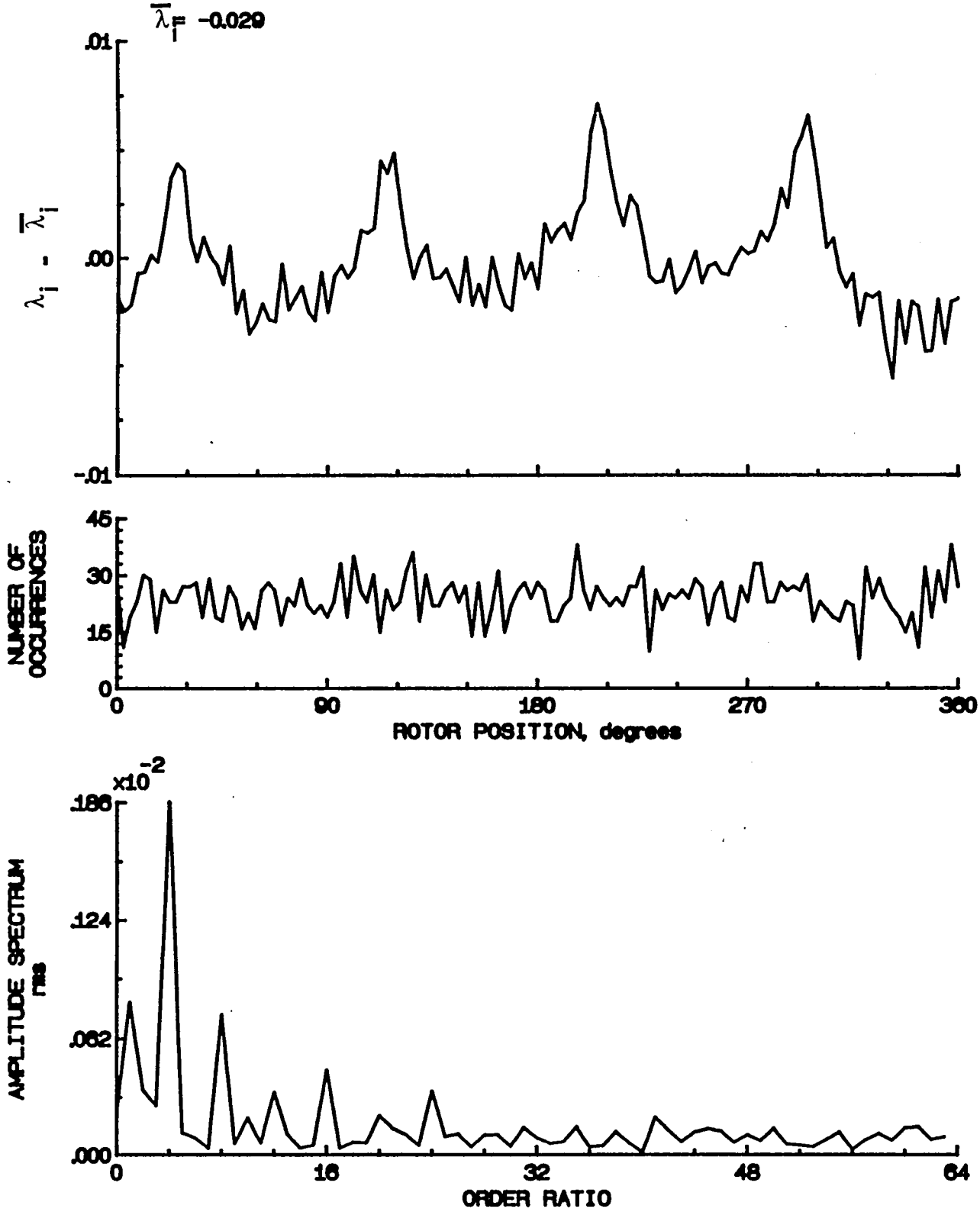


Figure 40.- Induced inflow velocity measured at 30 degrees and r/R of 1.02.



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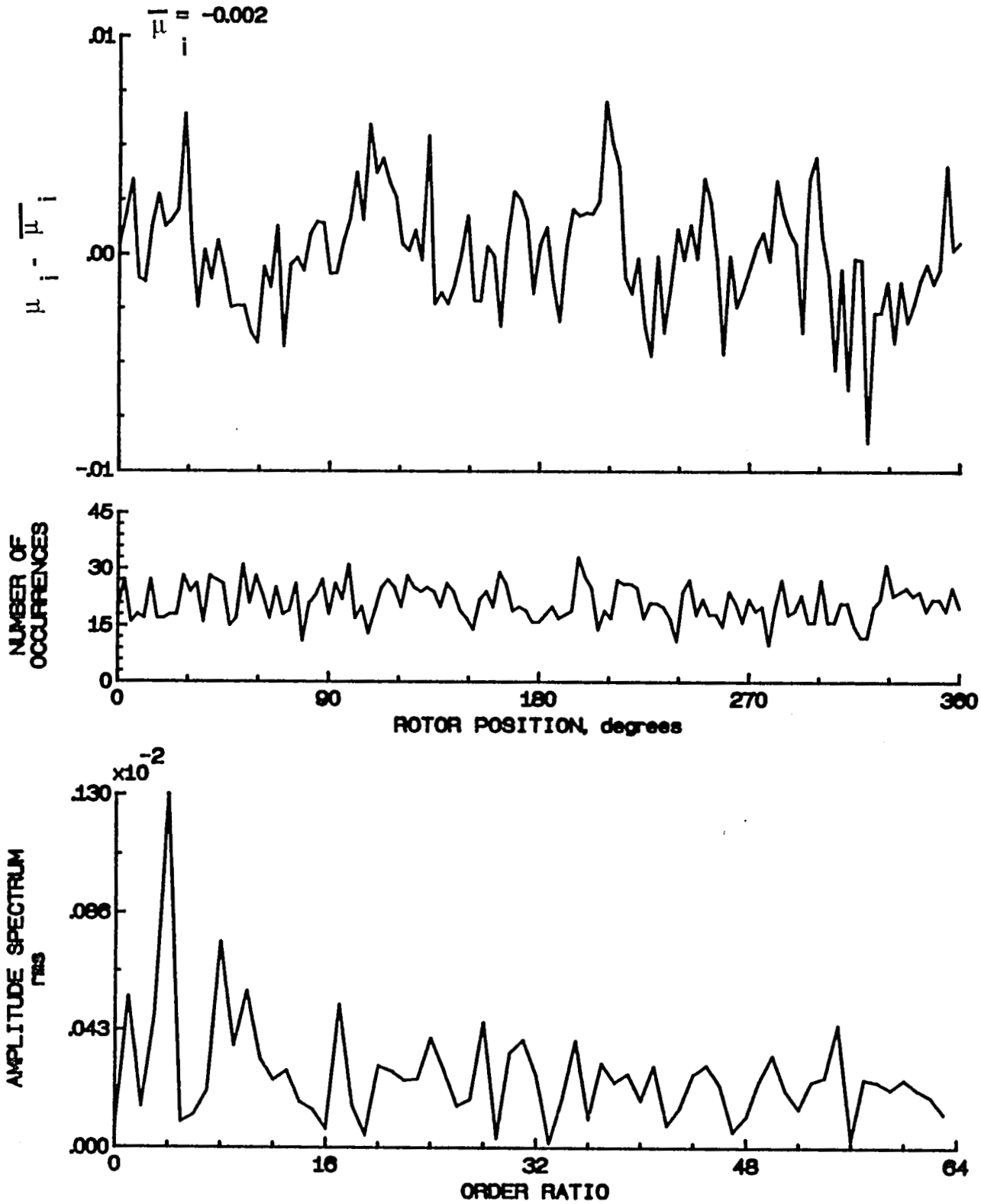
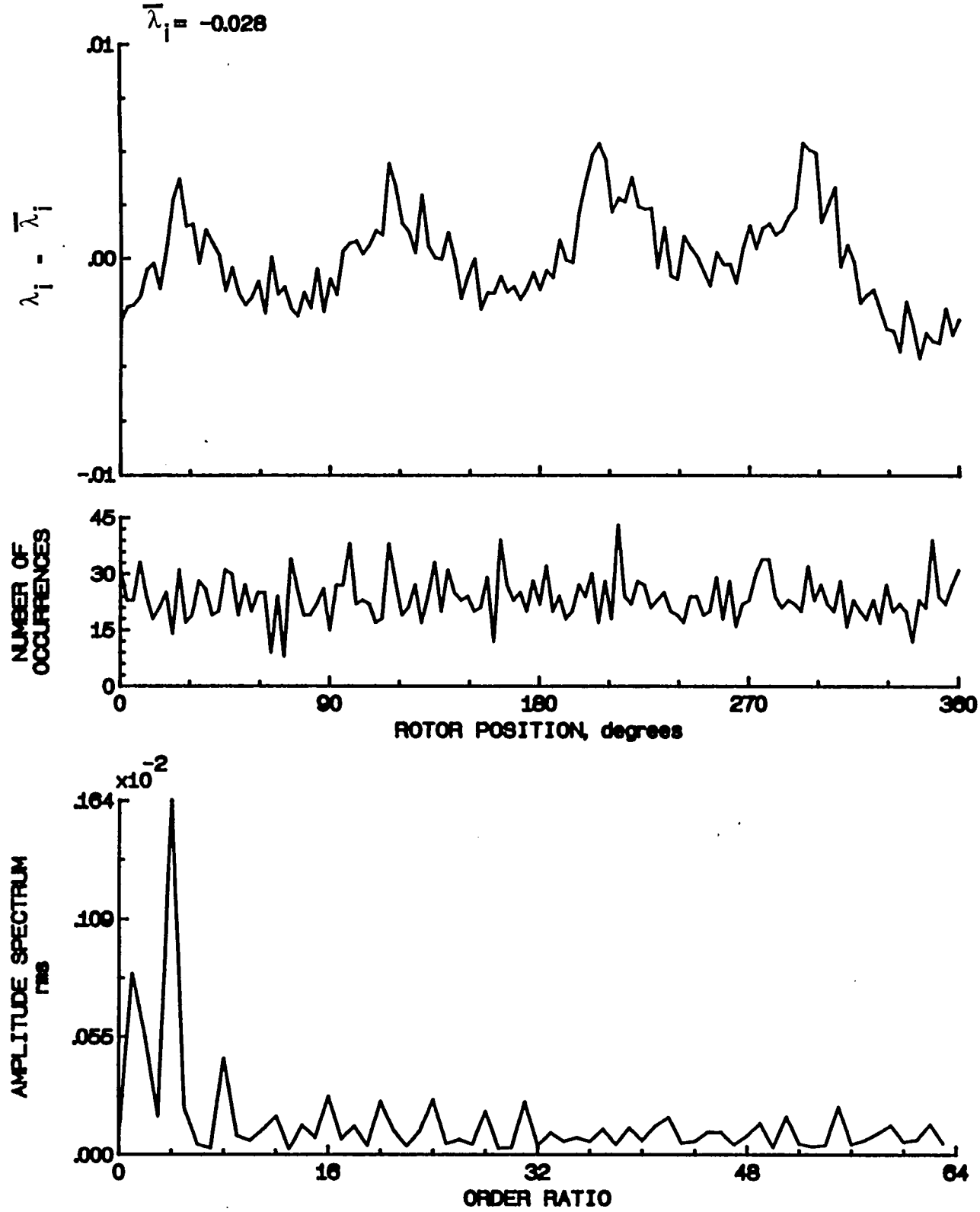


Figure 41.- Induced inflow velocity measured at 30 degrees and r/R of 1.04.



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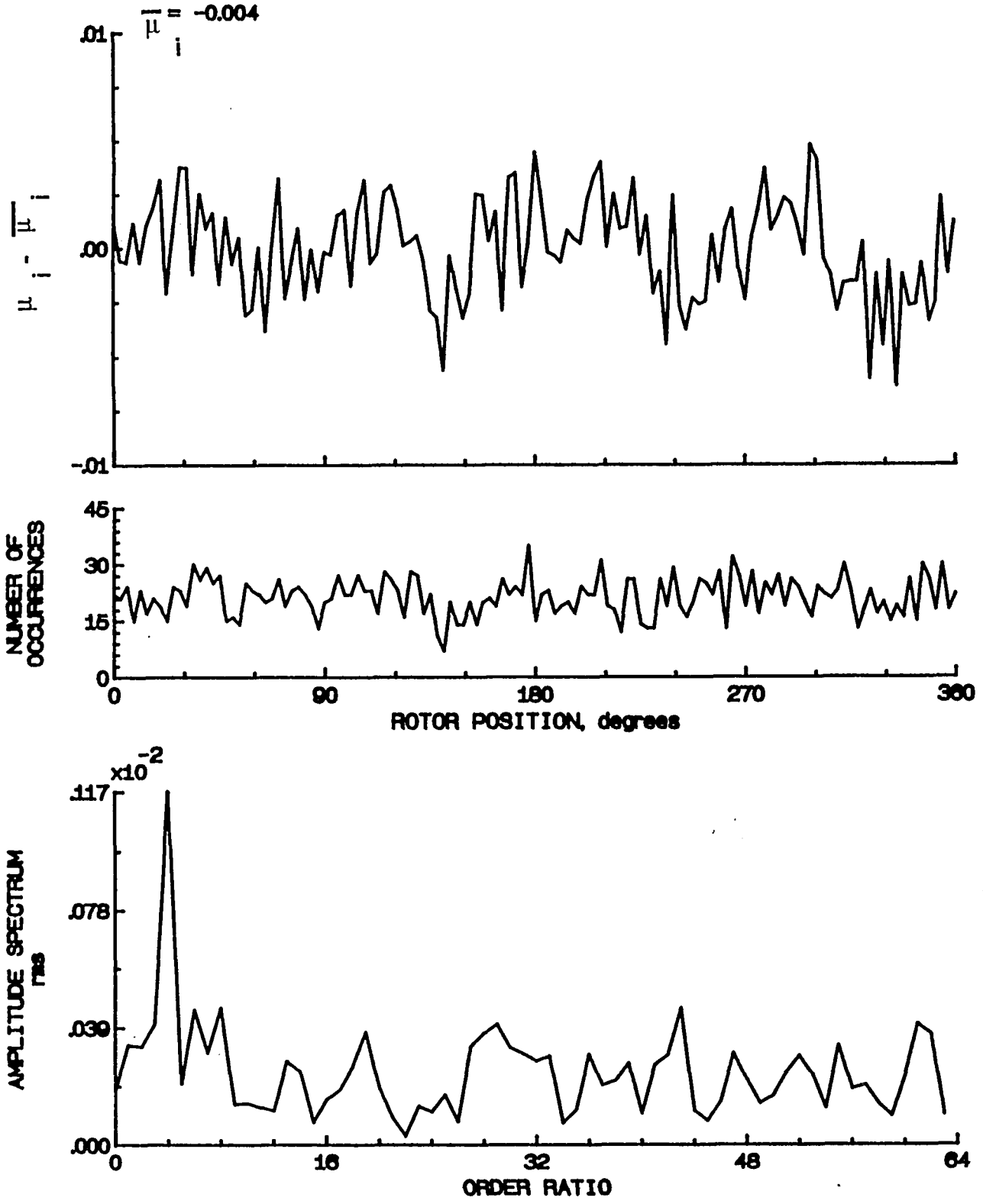
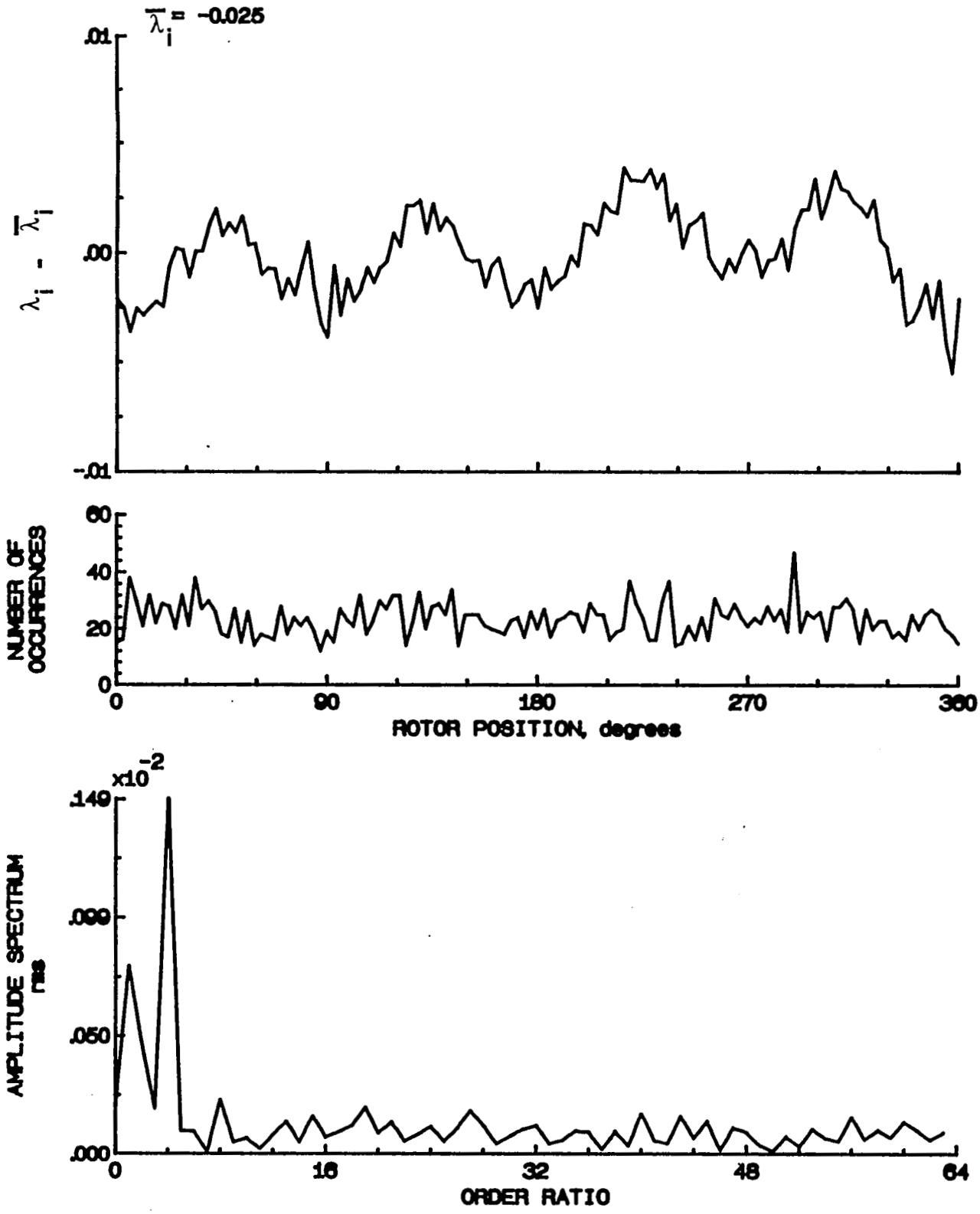


Figure 42.- Induced inflow velocity measured at 30 degrees and r/R of 1.10.



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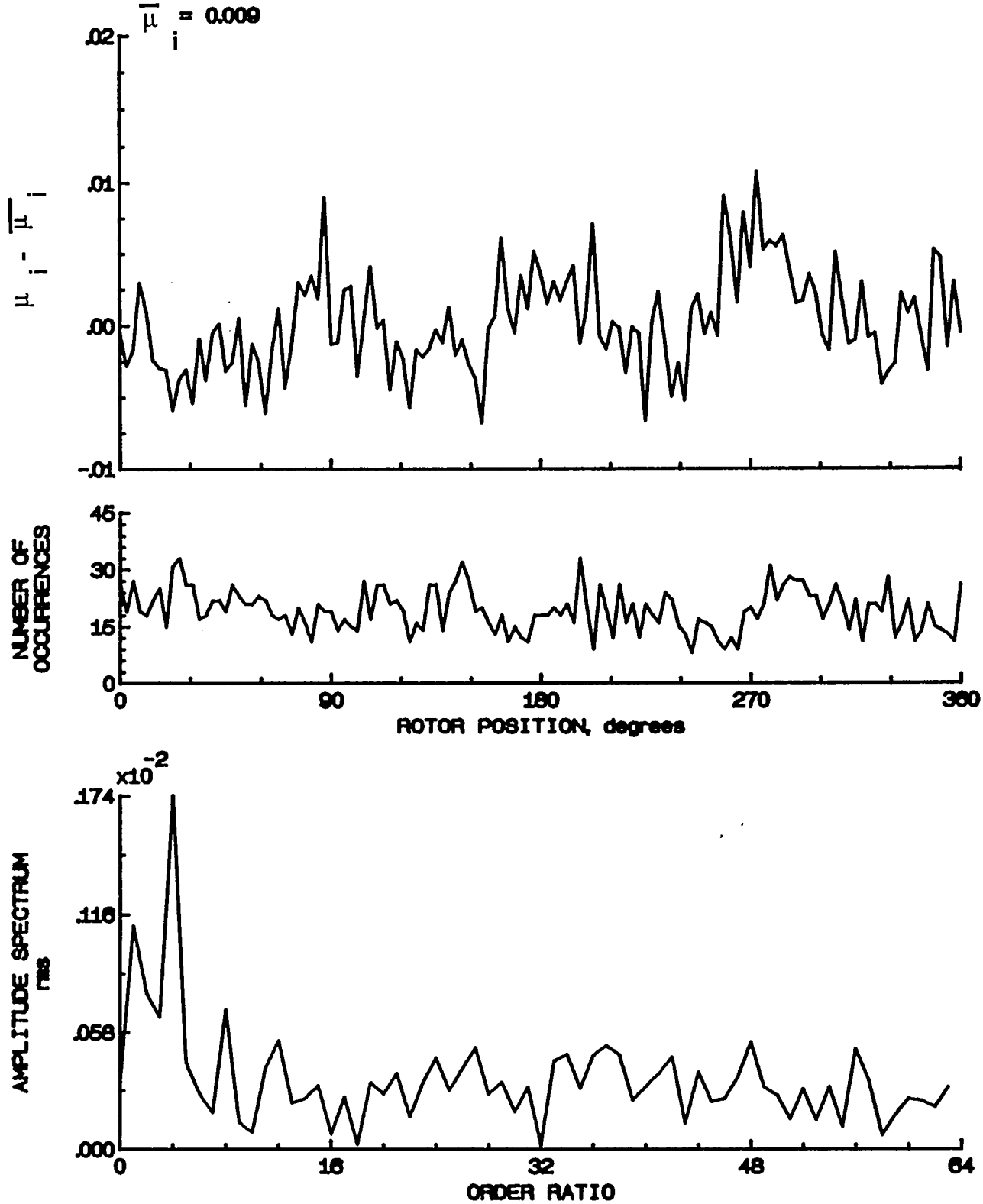
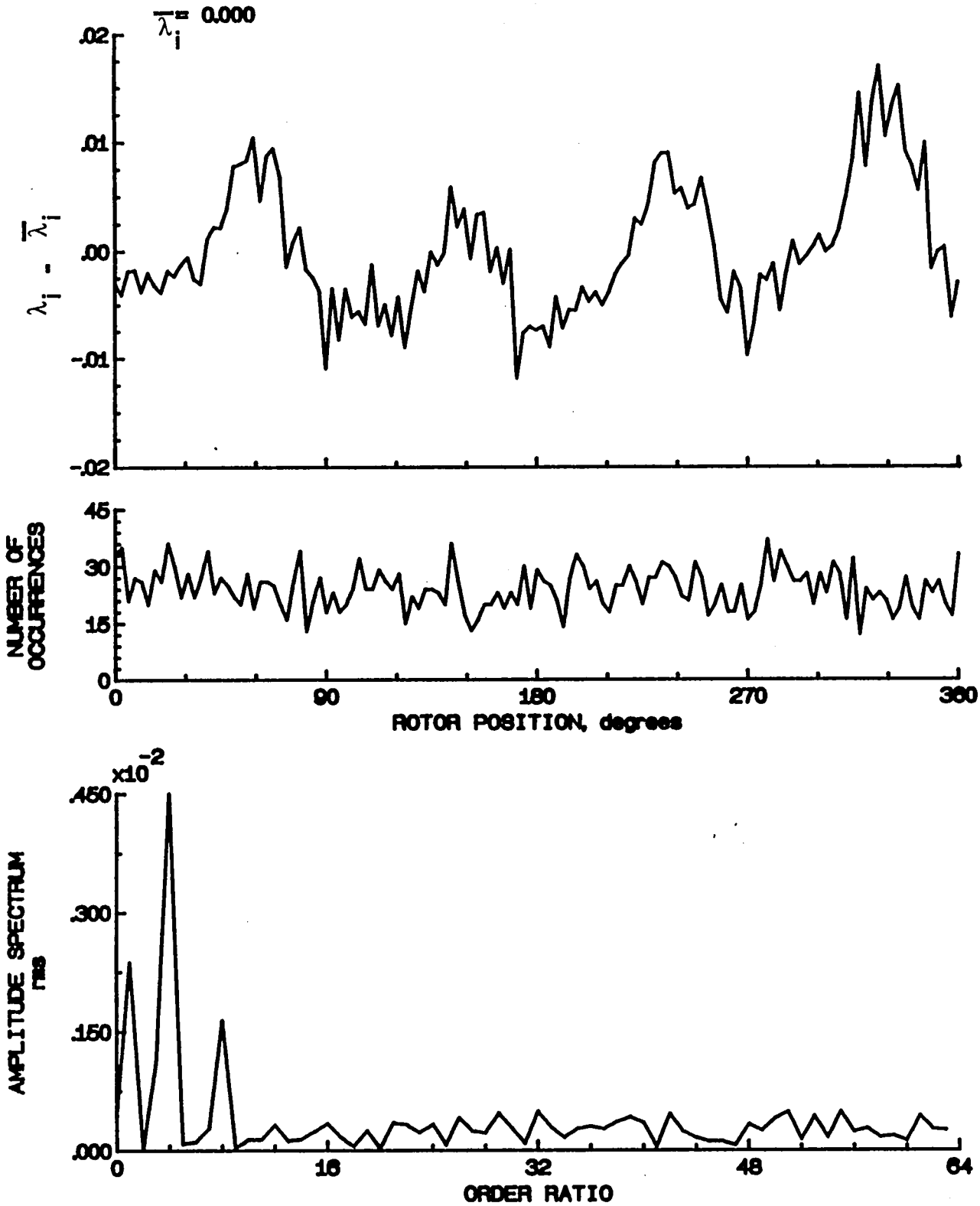


Figure 43.- Induced inflow velocity measured at 60 degrees and r/R of 0.20.



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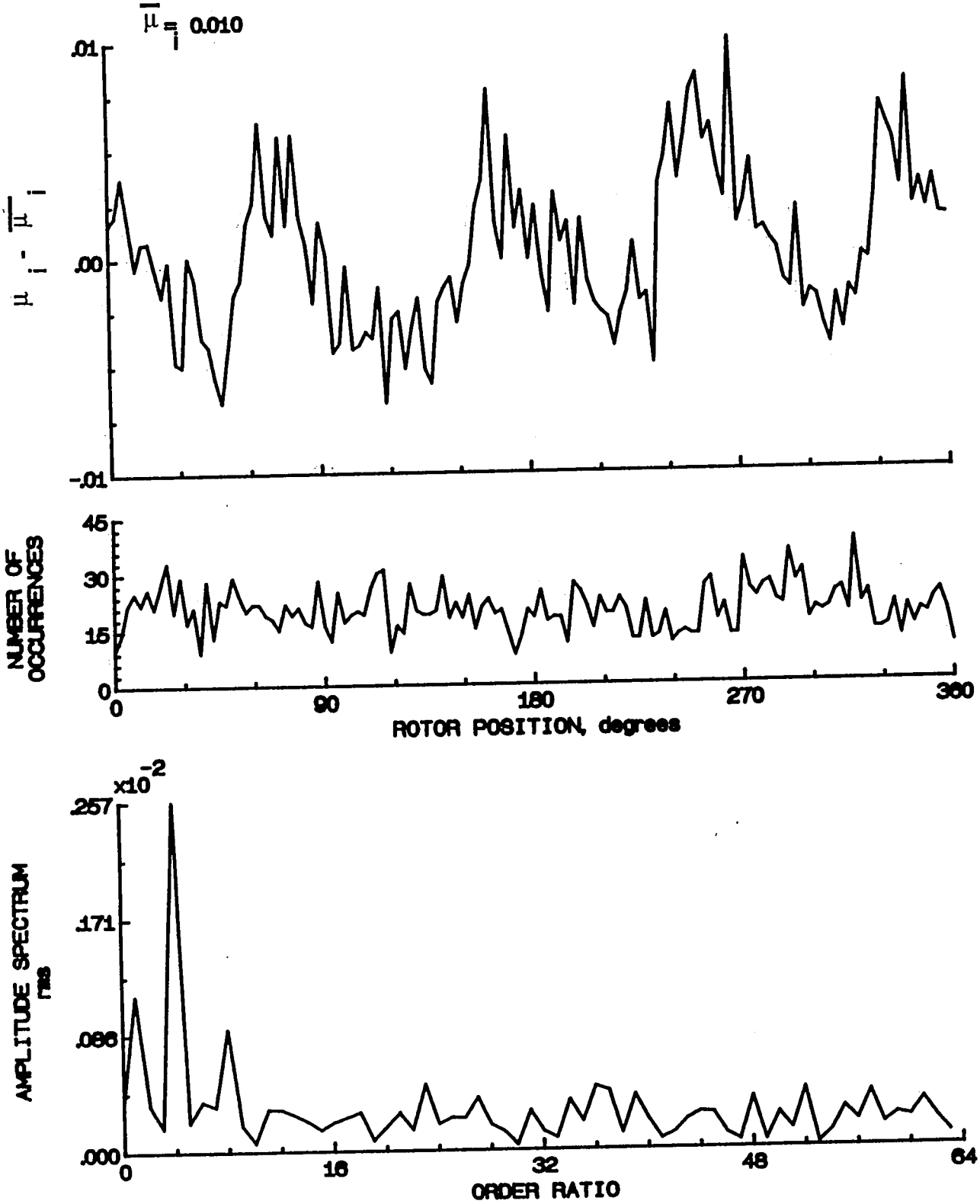
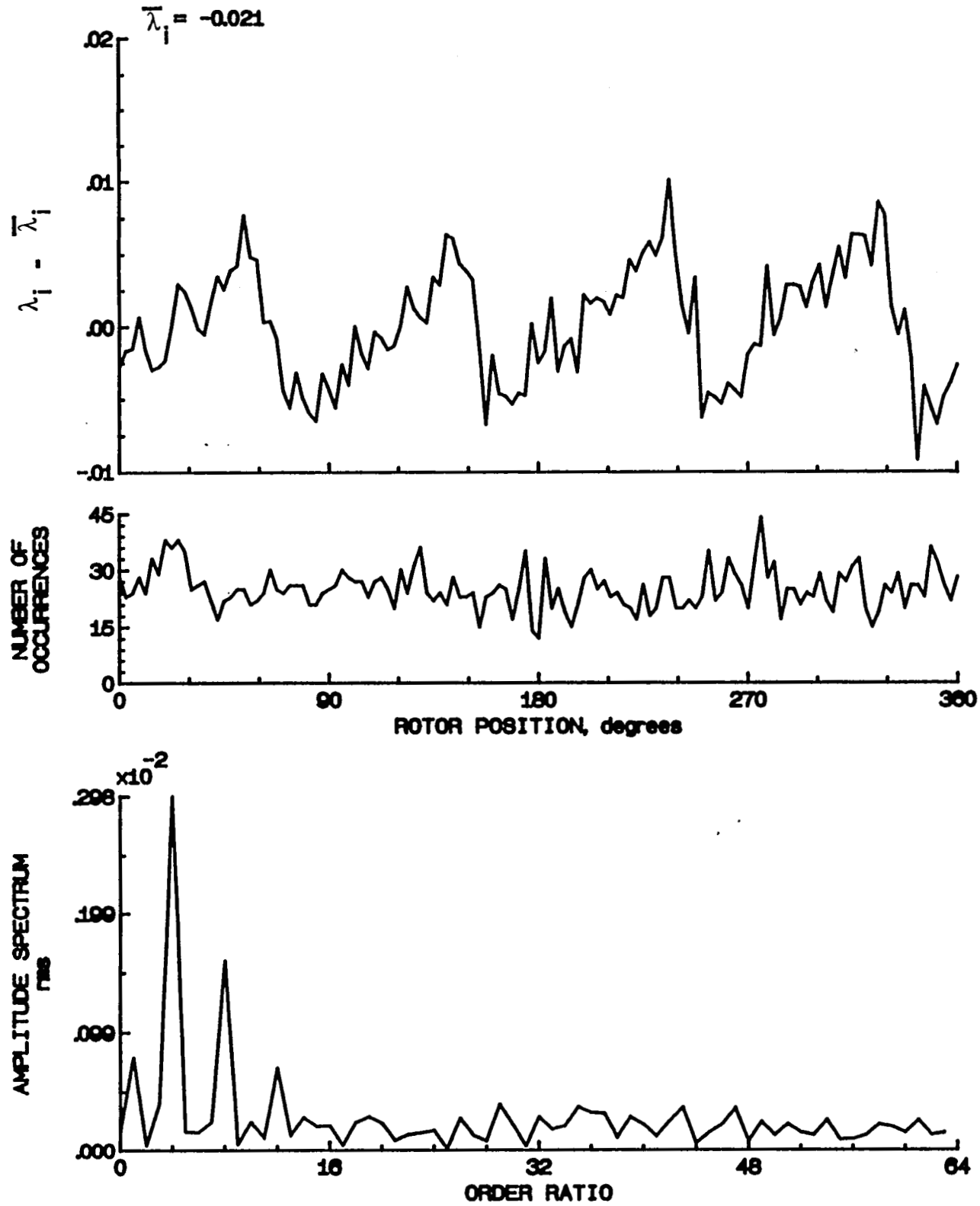


Figure 44.- Induced inflow velocity measured at 60 degrees and r/R of 0.40.



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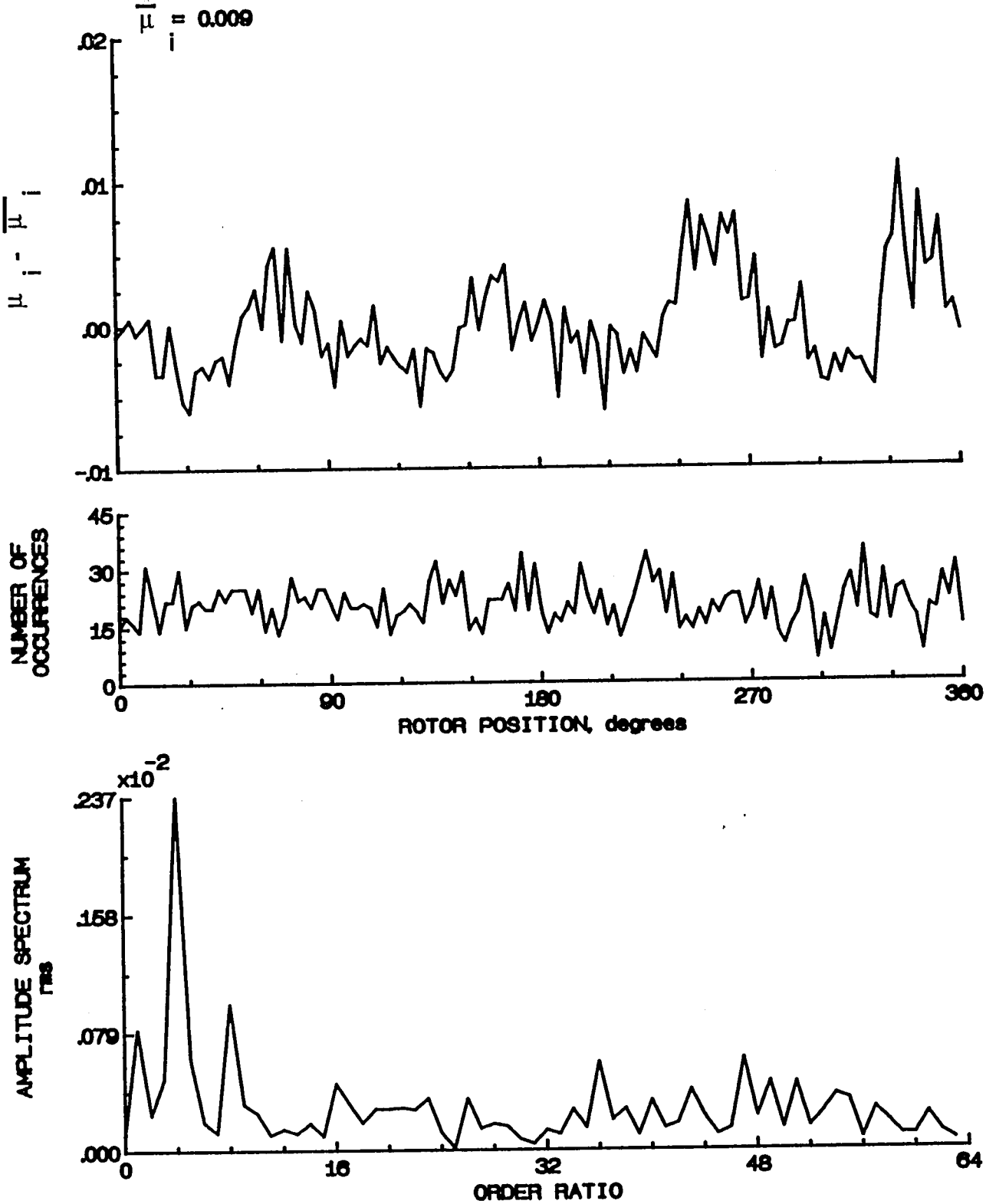
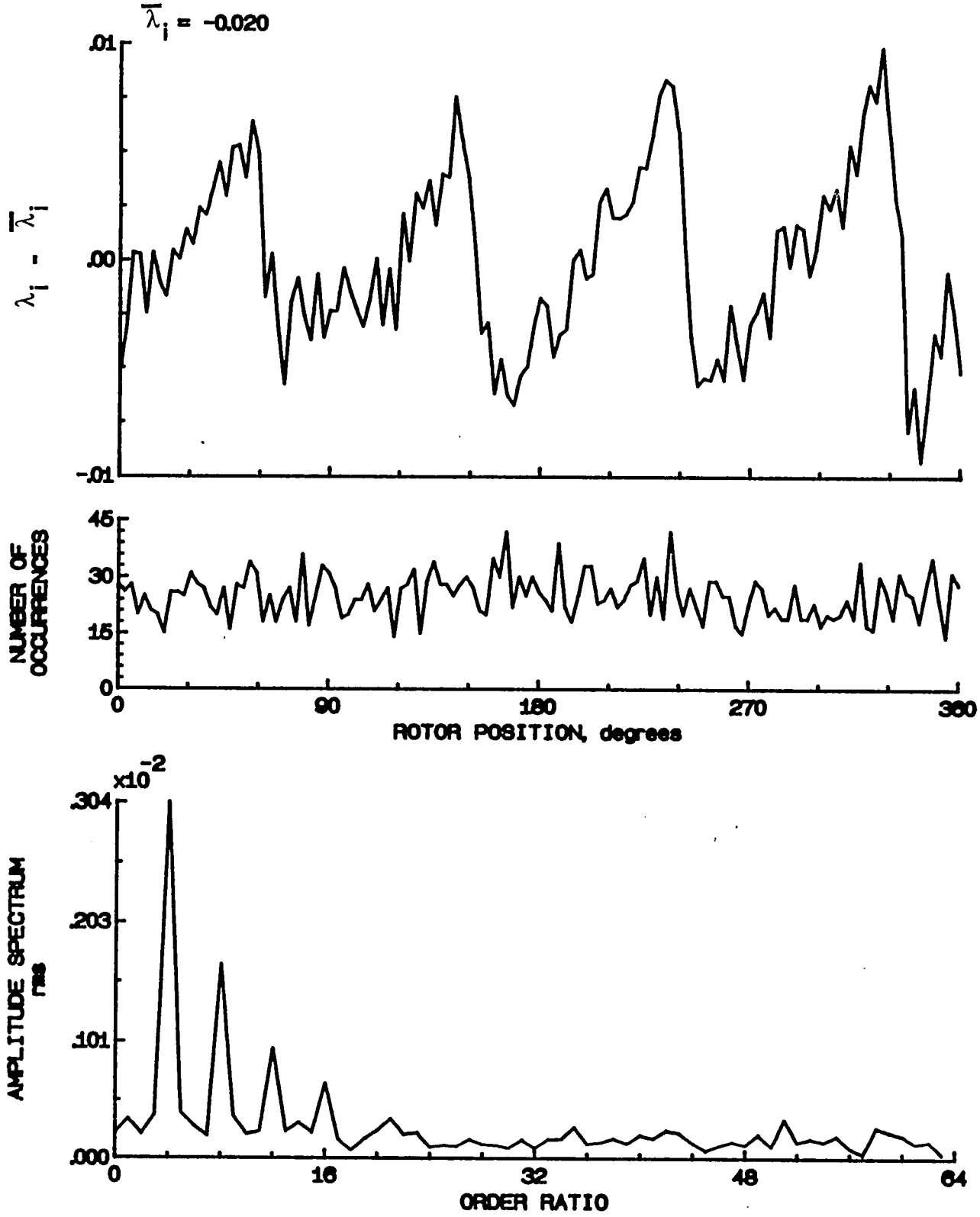


Figure 45.- Induced inflow velocity measured at 60 degrees and r/R of 0.50.



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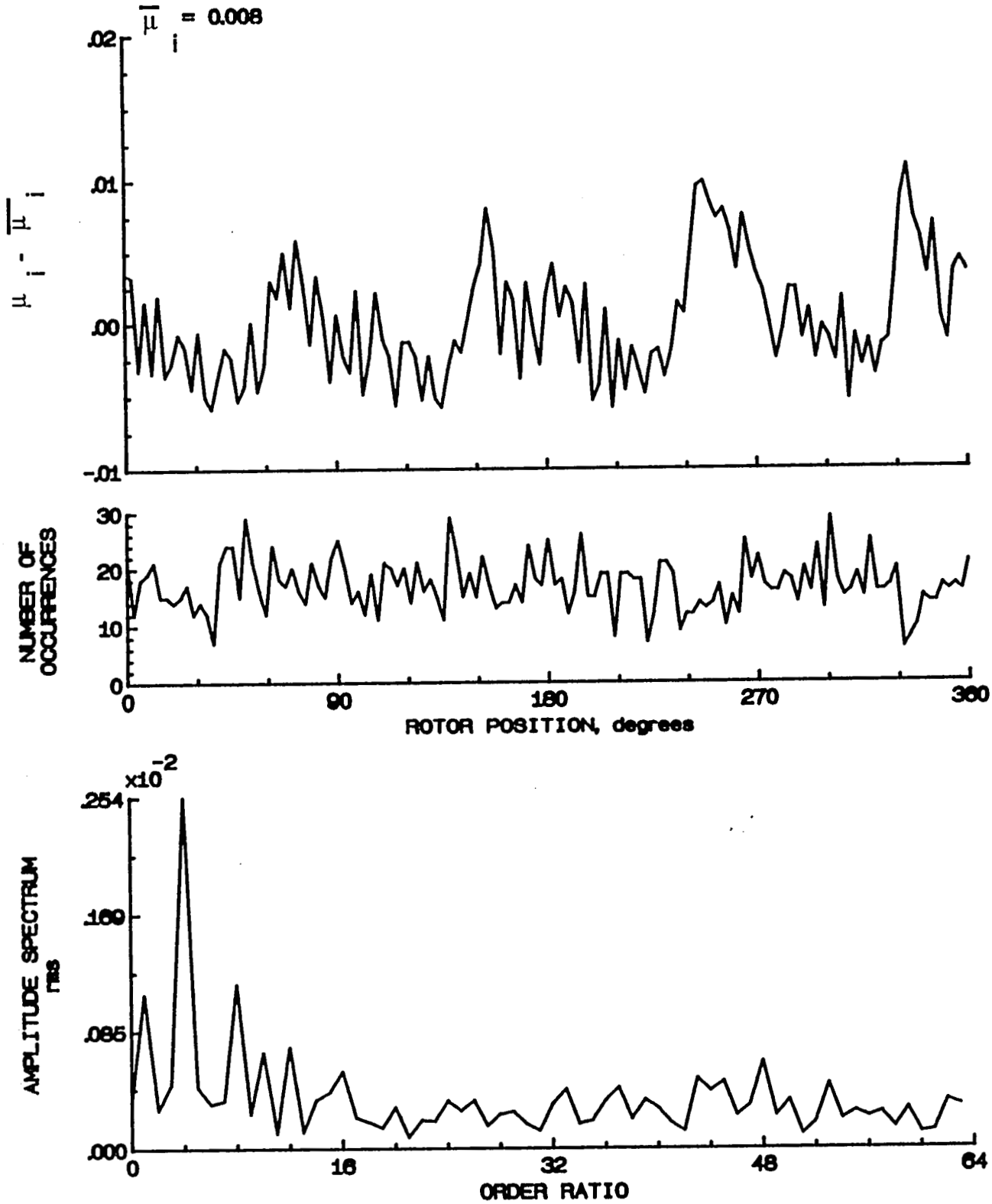
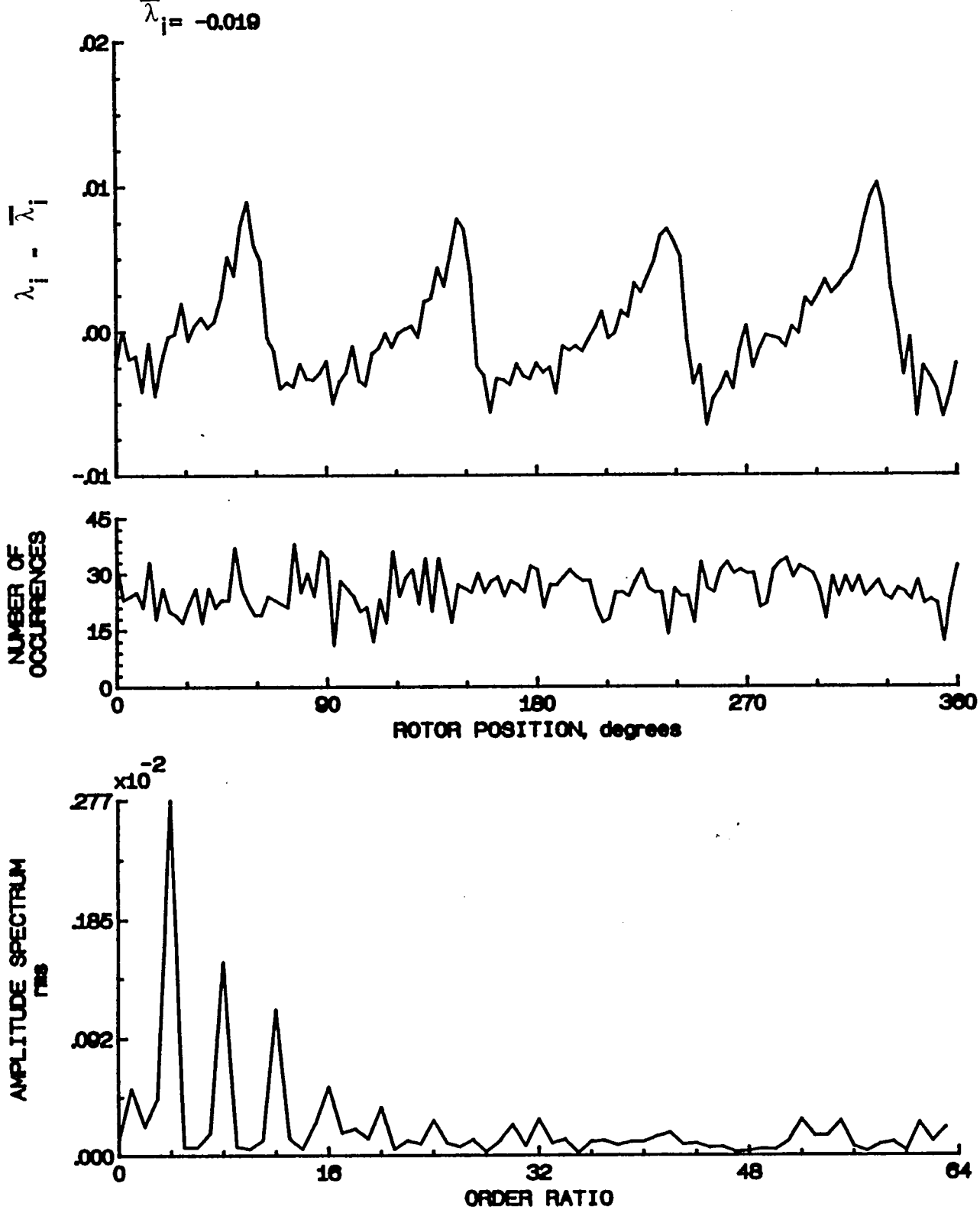


Figure 46.- Induced inflow velocity measured at 60 degrees and r/R of 0.60.



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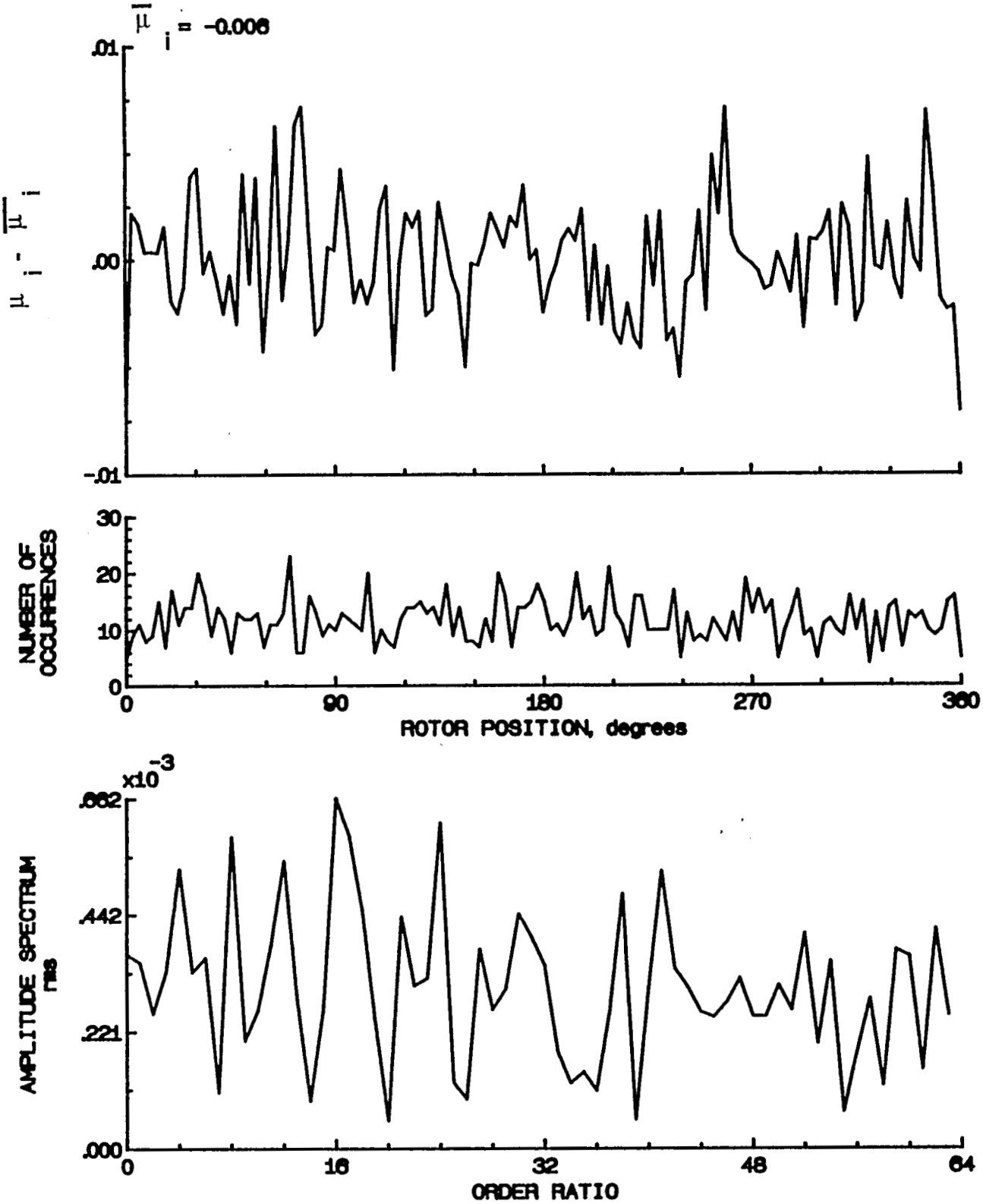
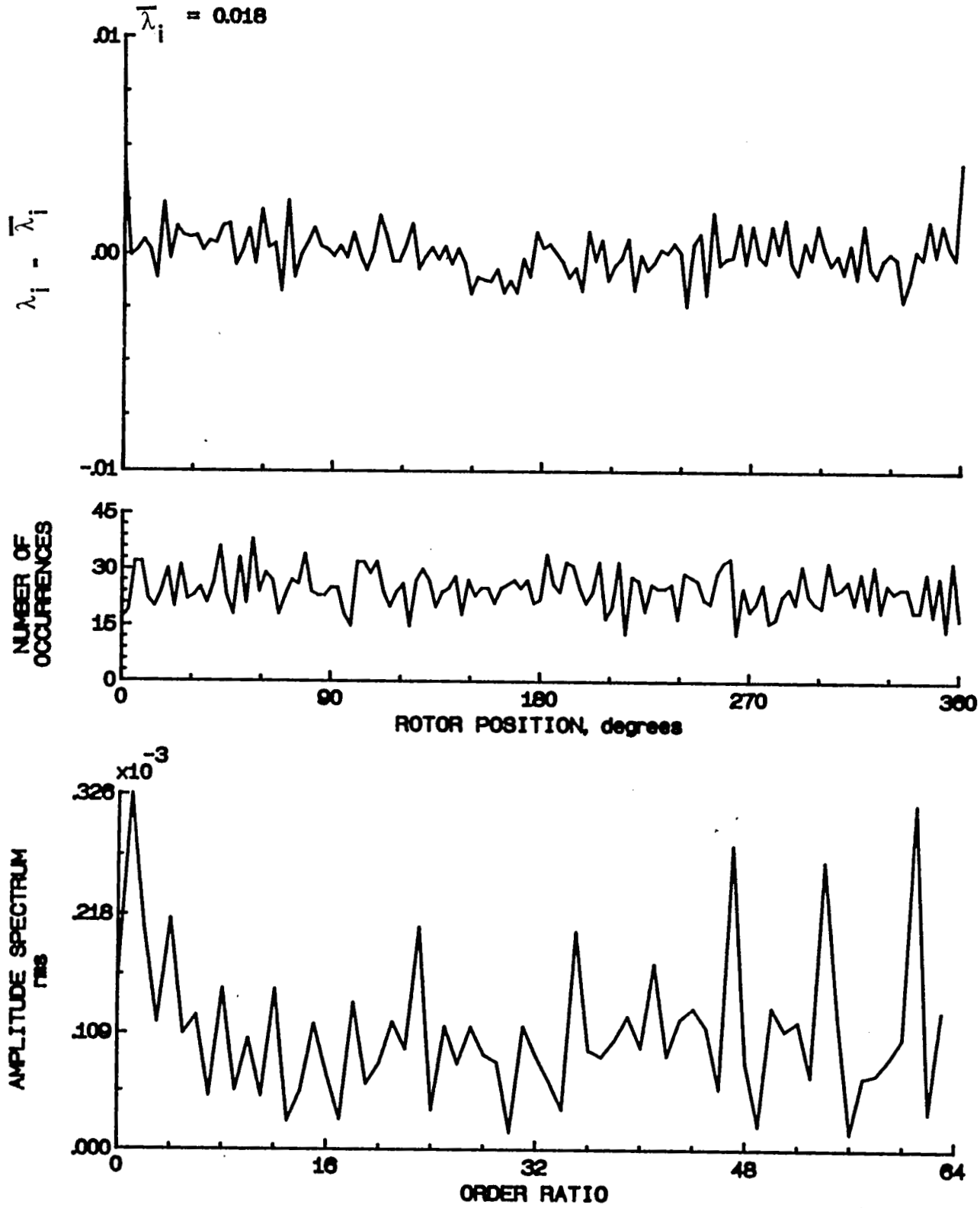


Figure 47.- Induced inflow velocity measured at 60 degrees and r/R of 0.70.



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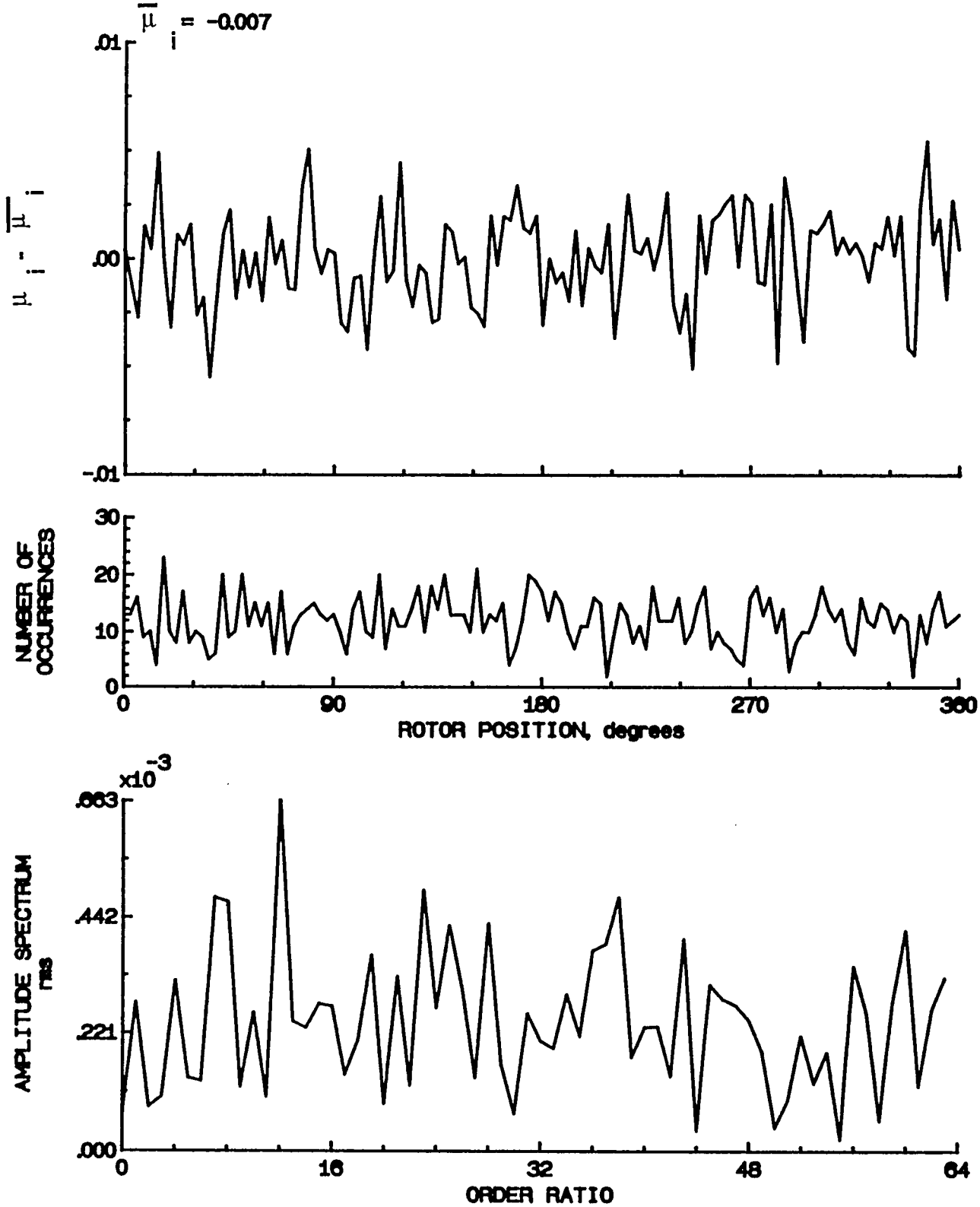
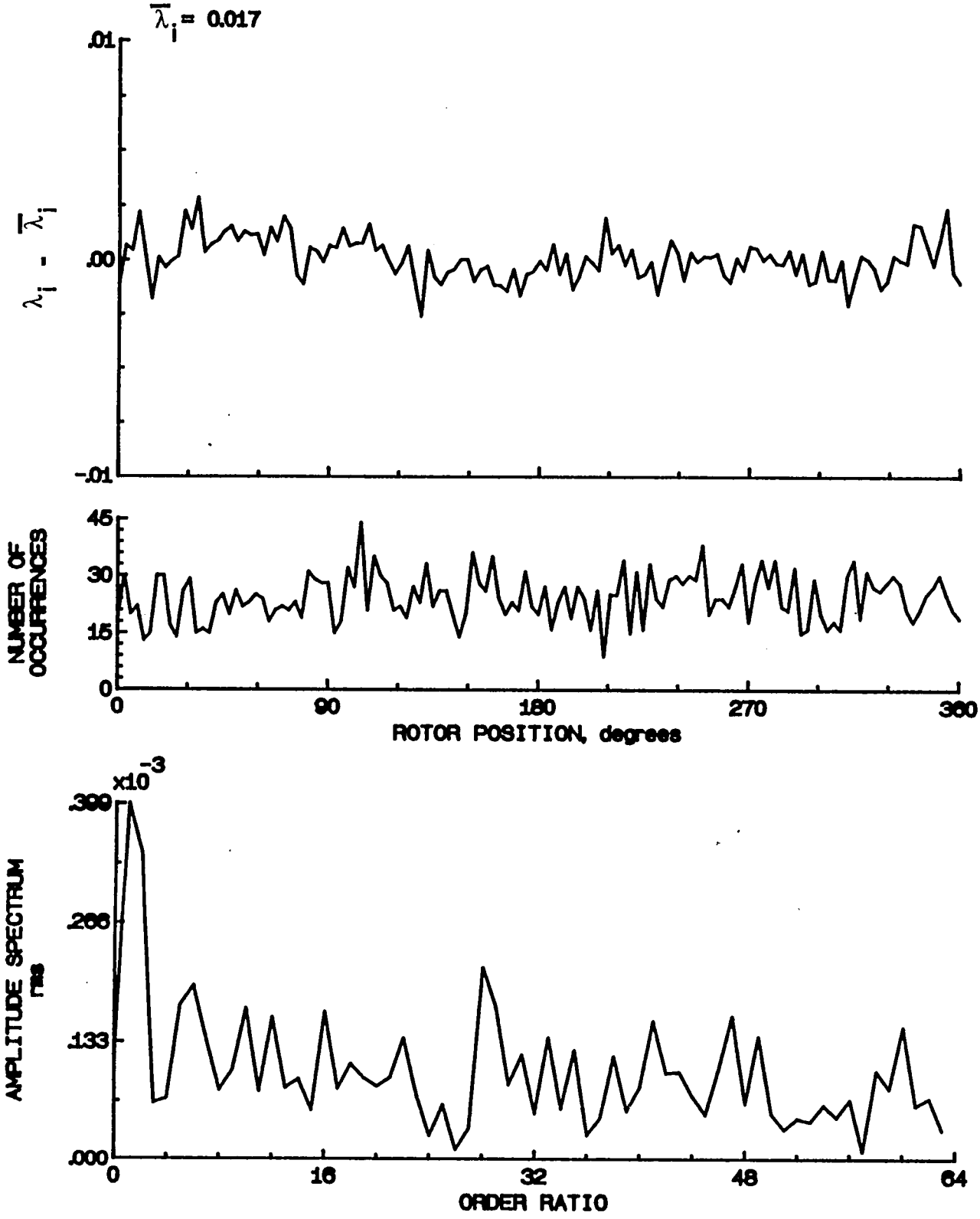


Figure 48.- Induced inflow velocity measured at 60 degrees and r/R of 0.74.



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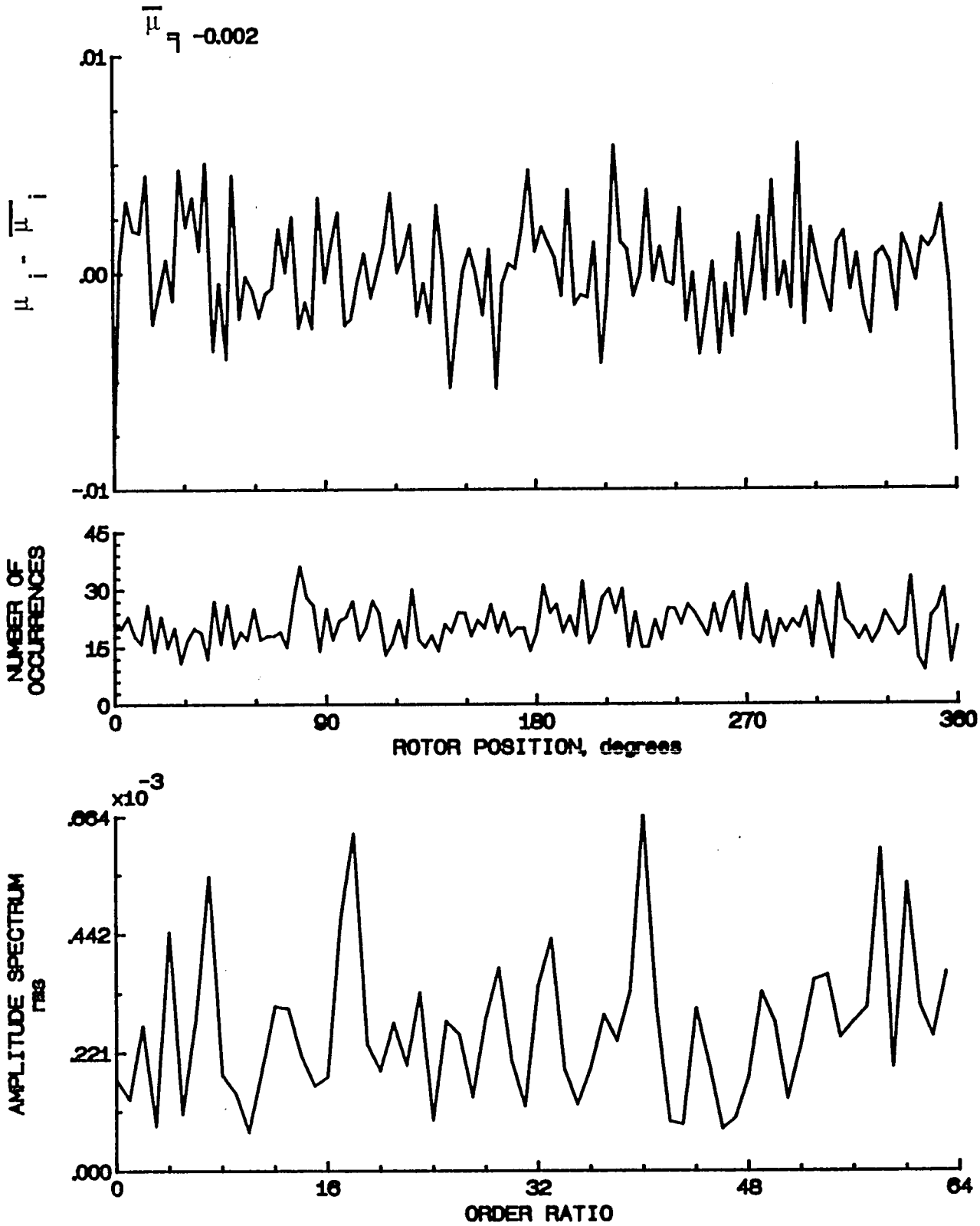
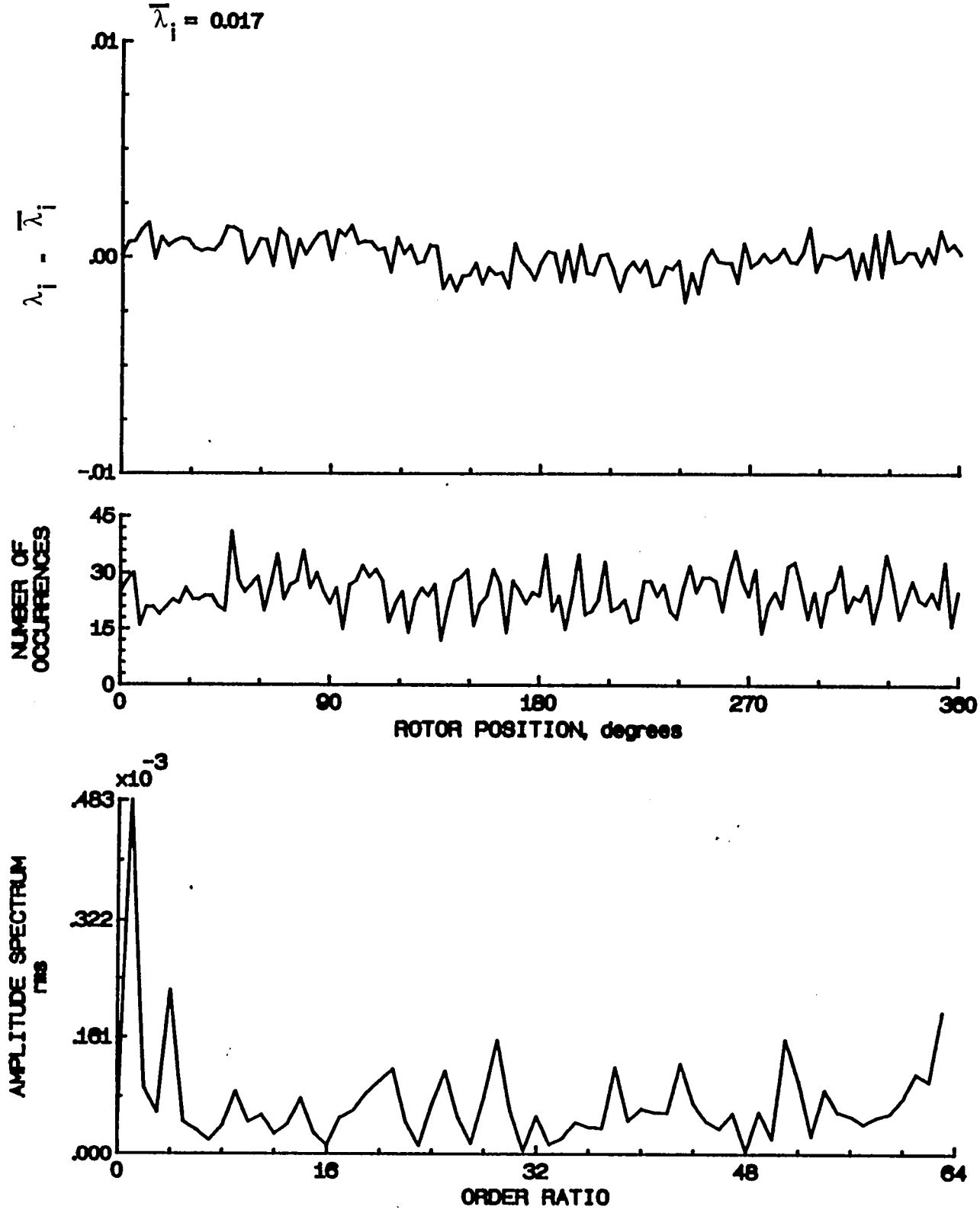


Figure 49.- Induced inflow velocity measured at 60 degrees and r/R of 0.78.



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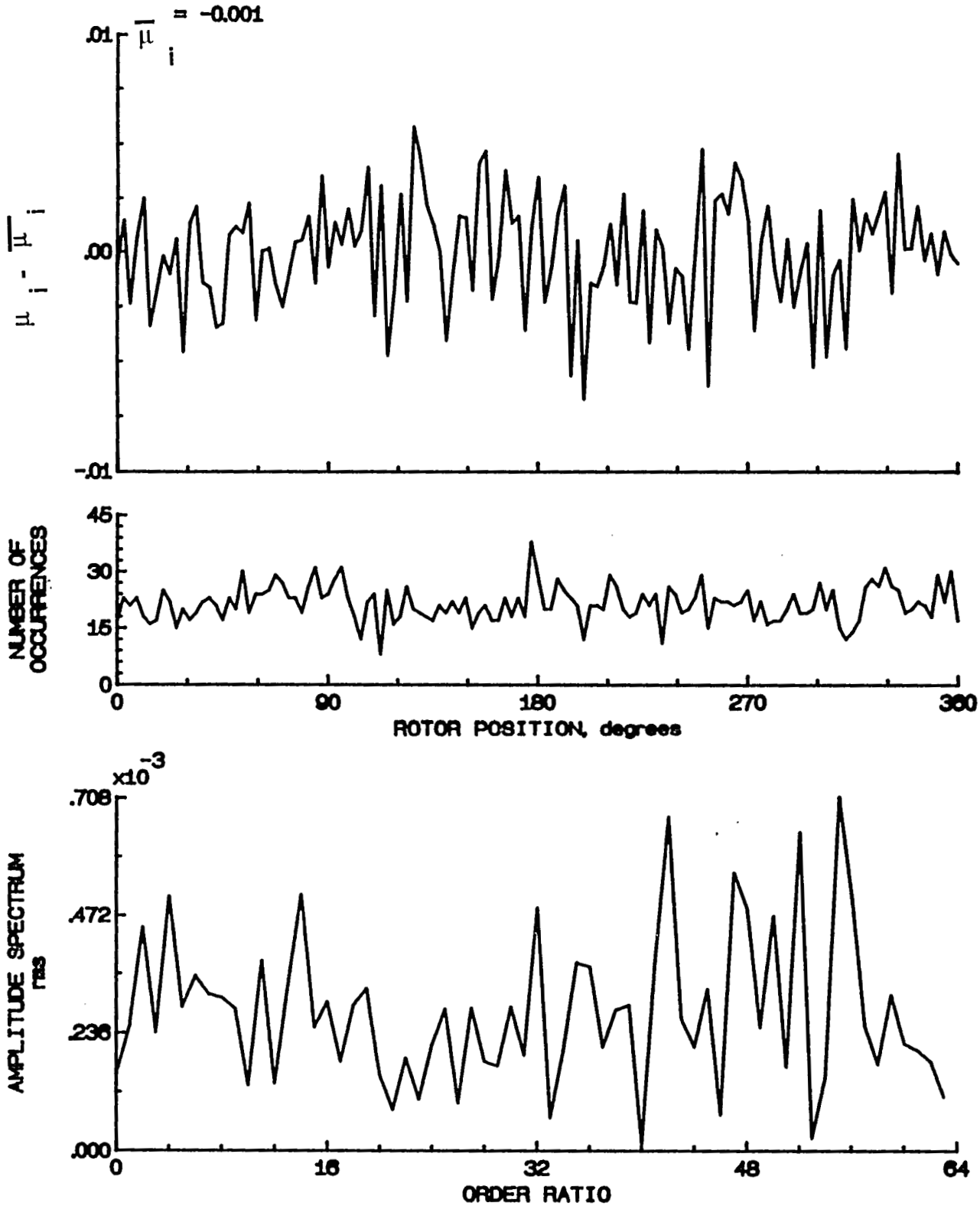
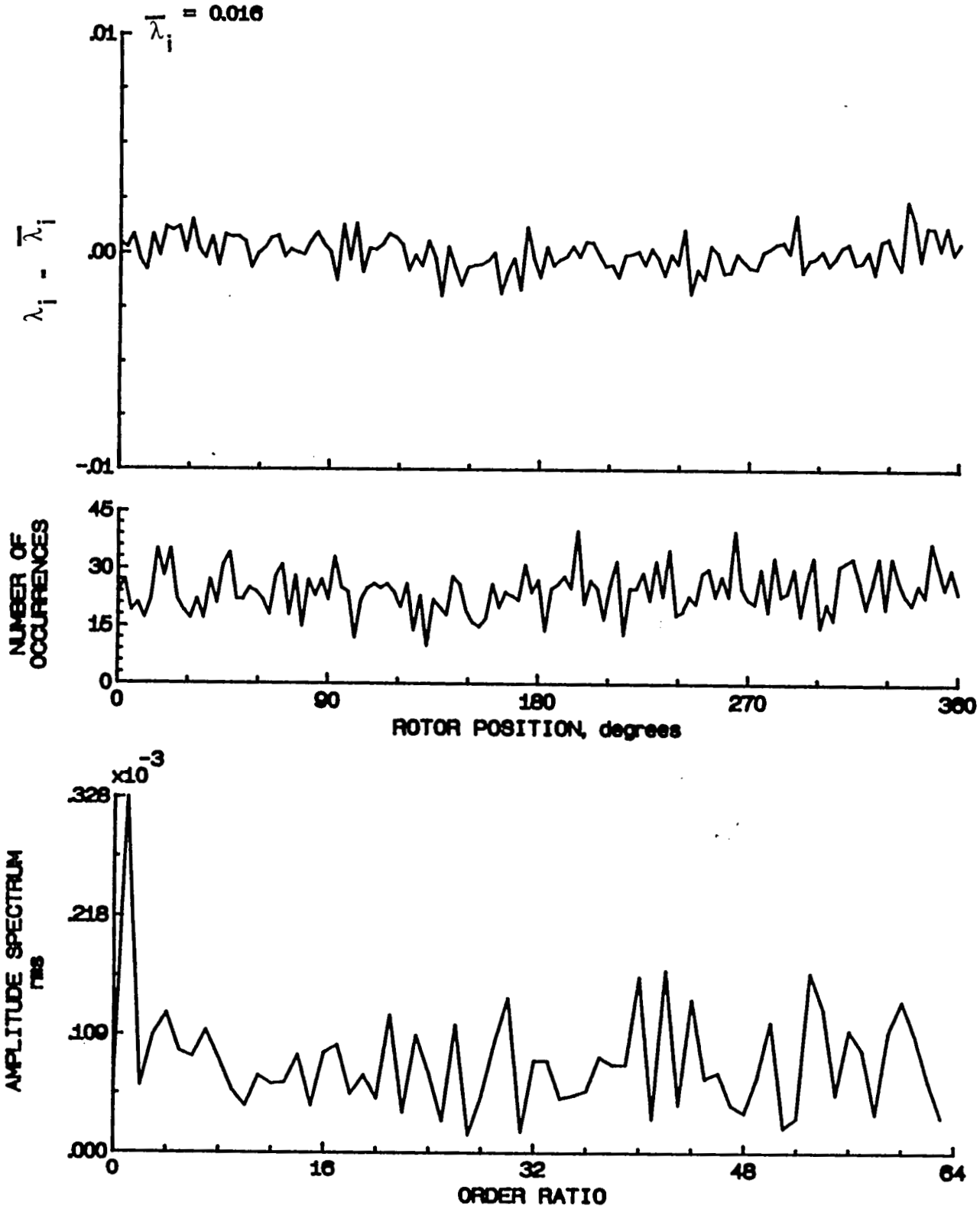


Figure 50.- Induced inflow velocity measured at 60 degrees and r/R of 0.82.



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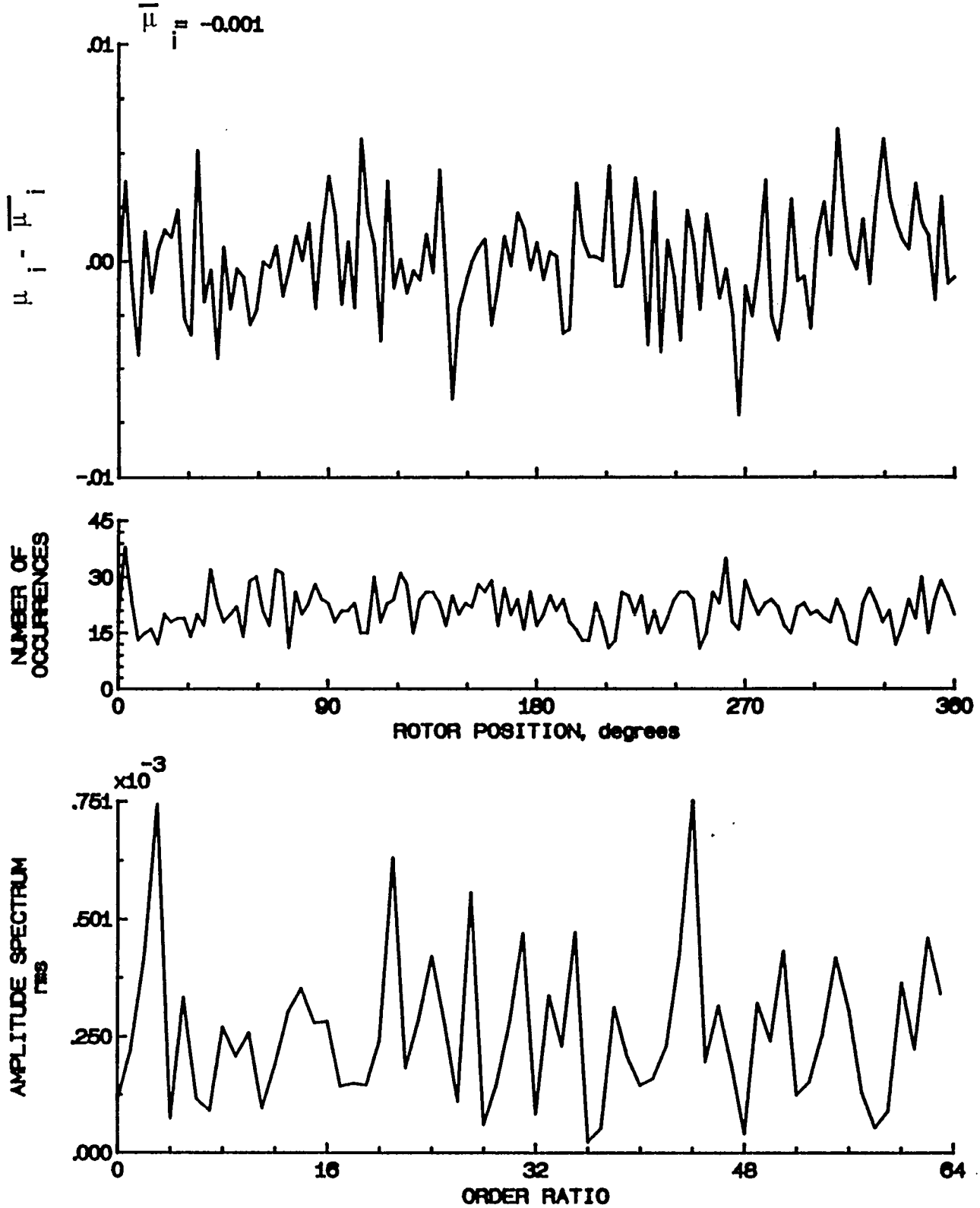
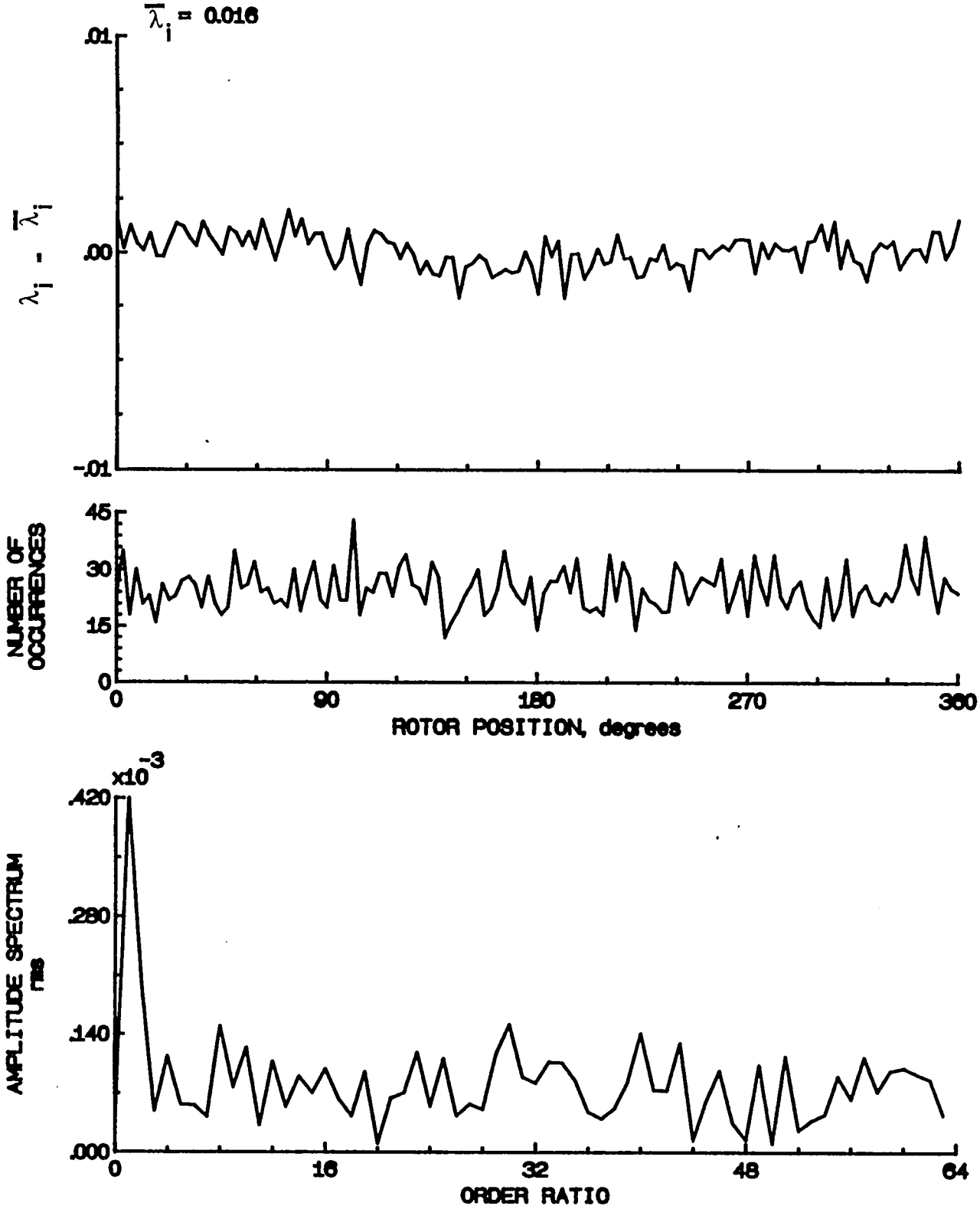


Figure 51.- Induced inflow velocity measured at 60 degrees and r/R of 0.86.



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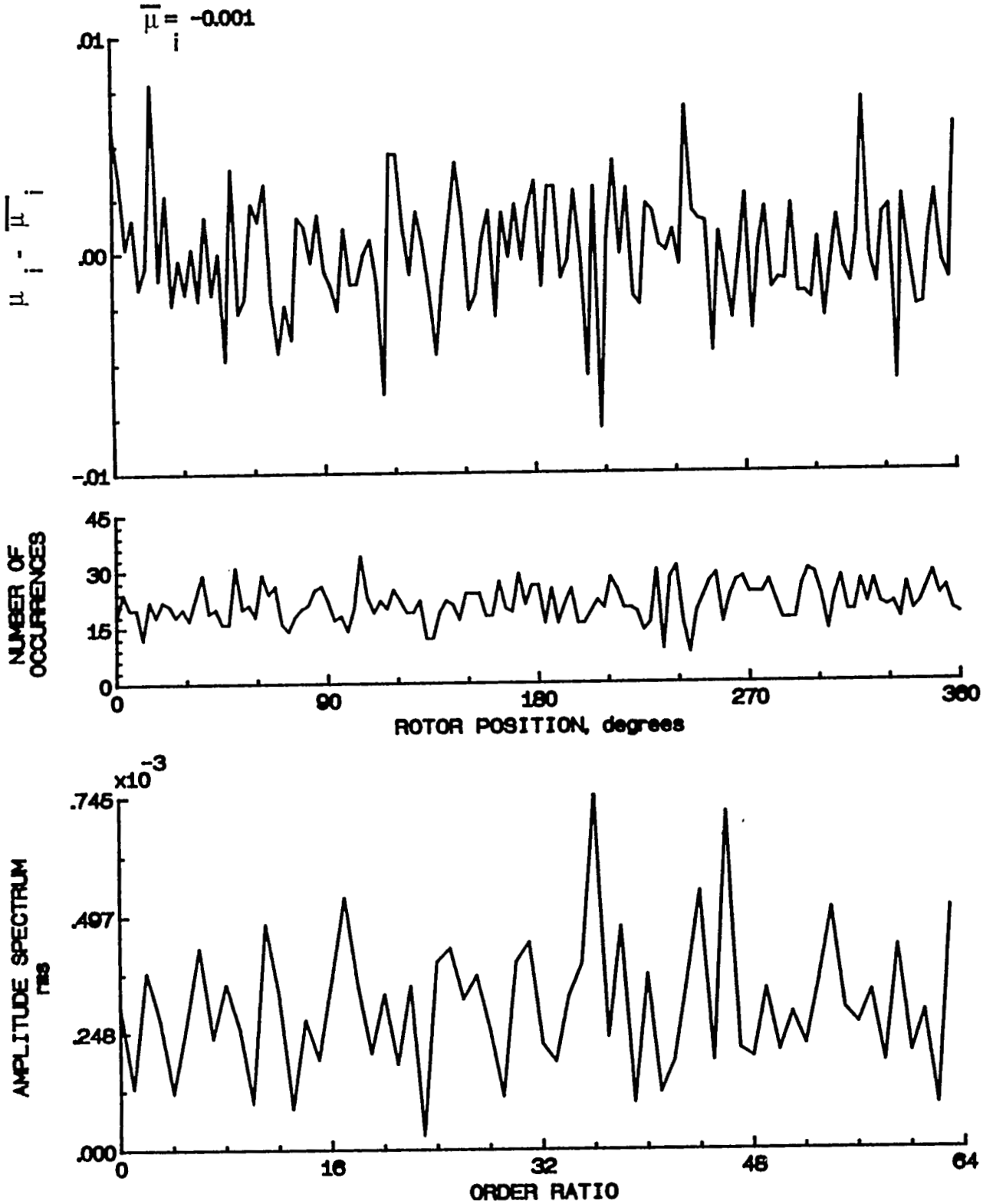
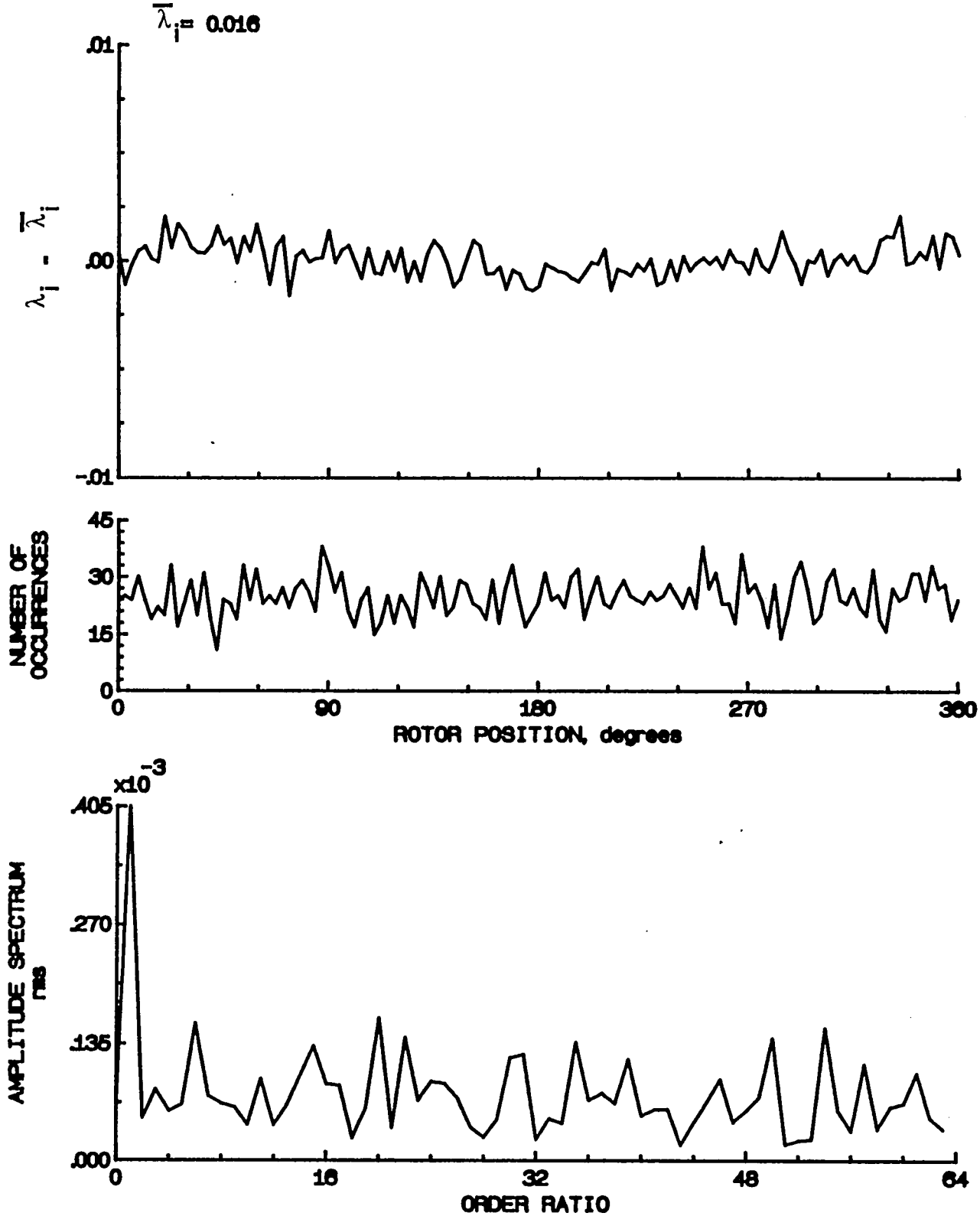


Figure 52.- Induced inflow velocity measured at 60 degrees and r/R of 0.90.



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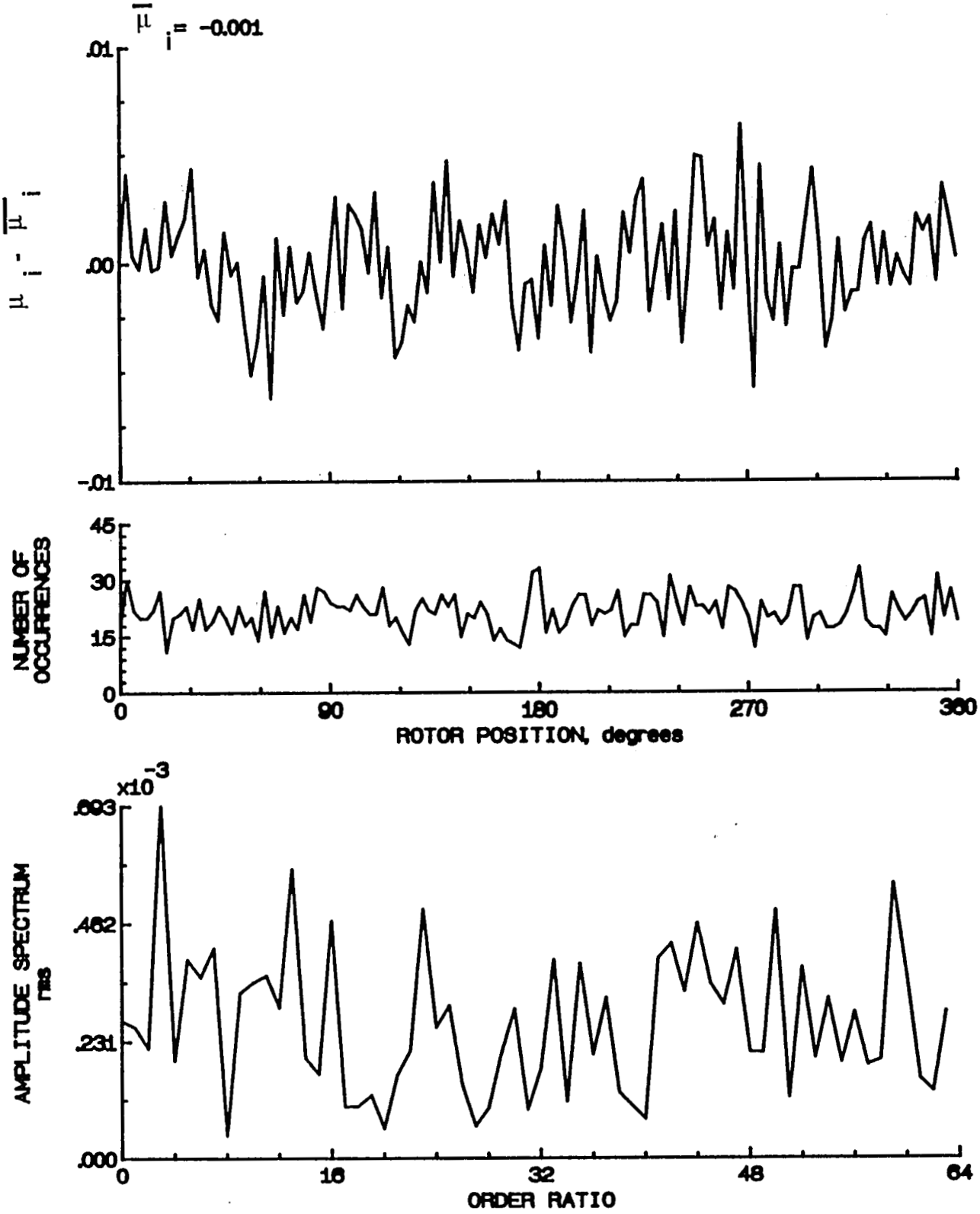
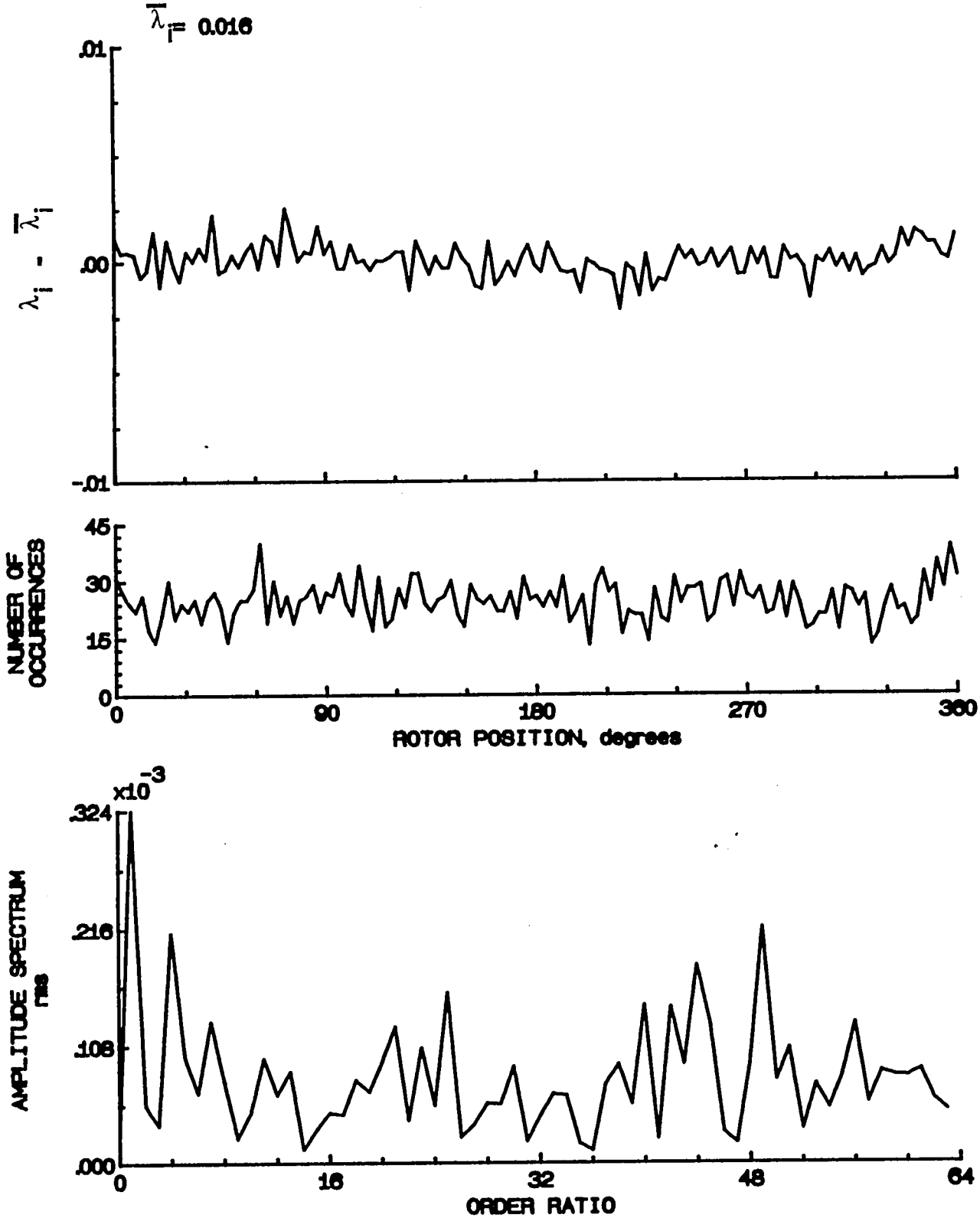


Figure 53.- Induced inflow velocity measured at 60 degrees and r/R of 0.94.



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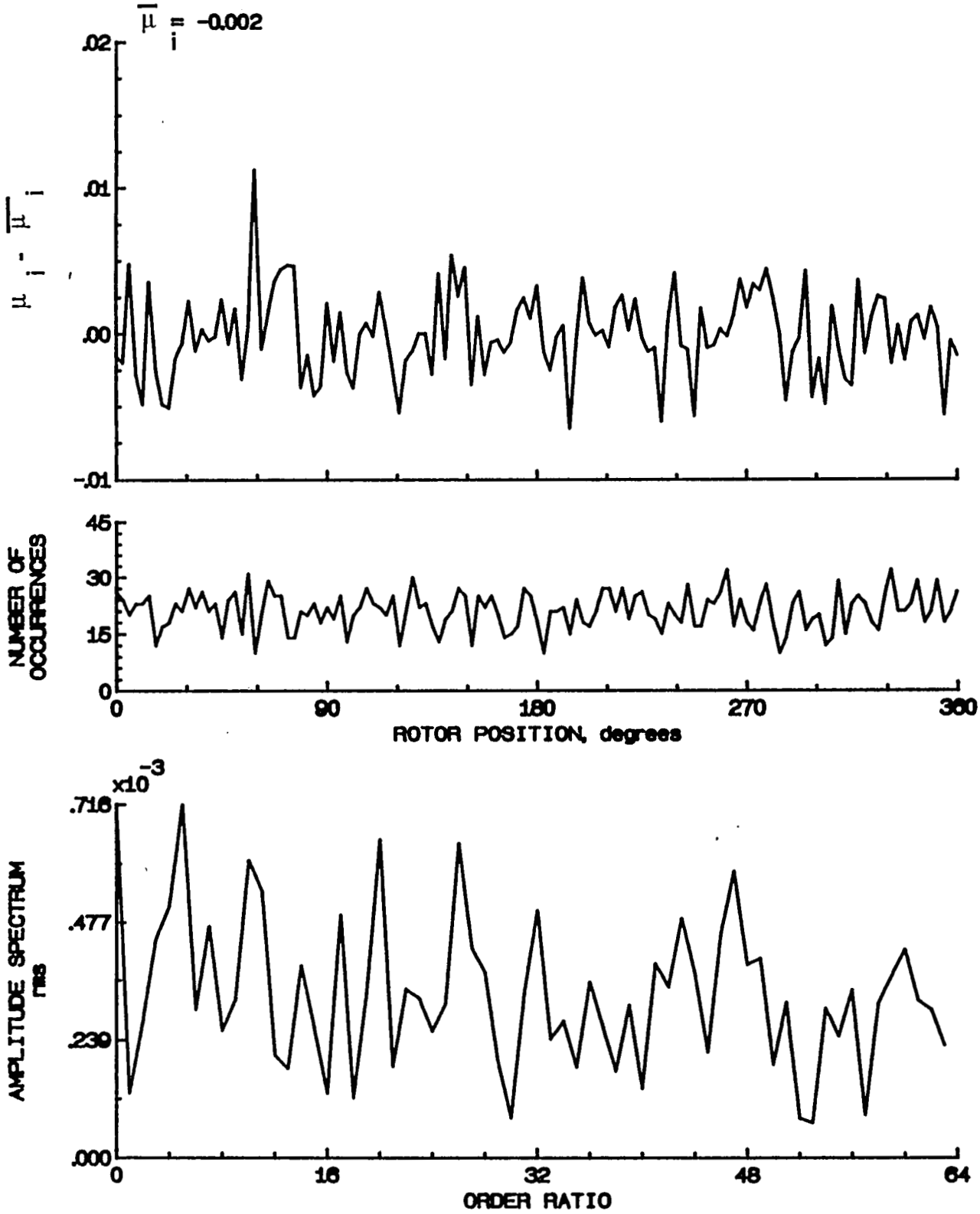
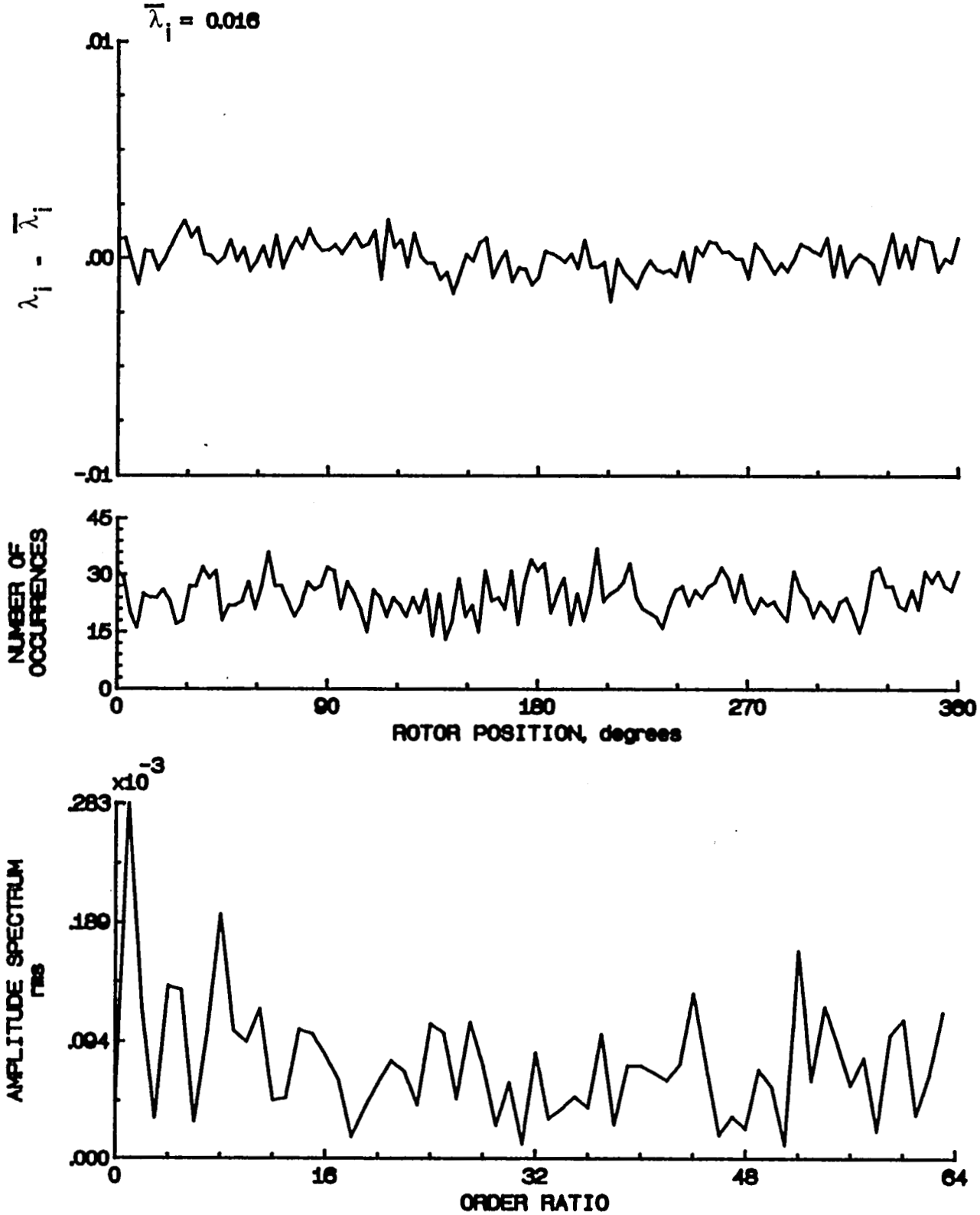


Figure 54.- Induced inflow velocity measured at 60 degrees and r/R of 0.98.



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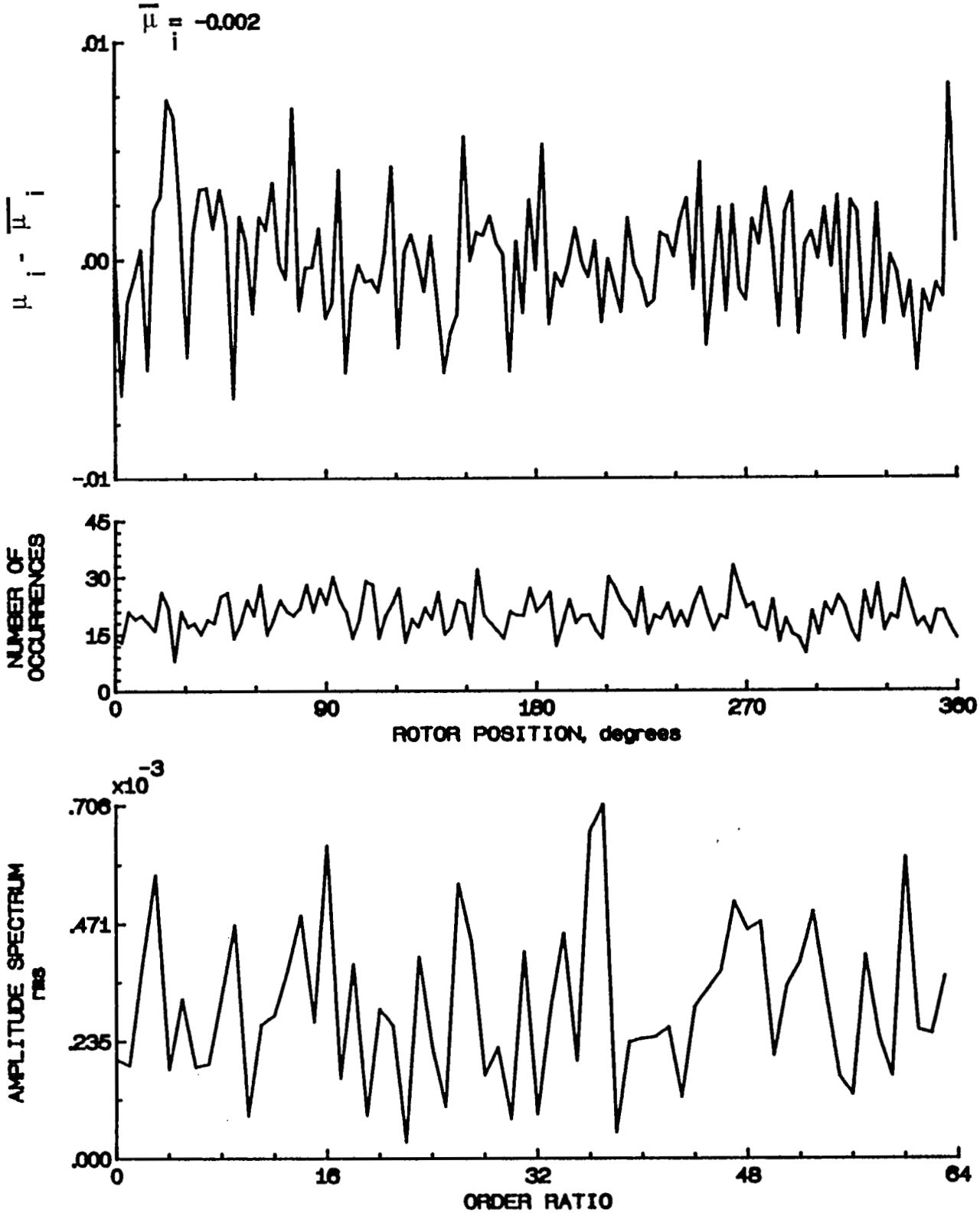
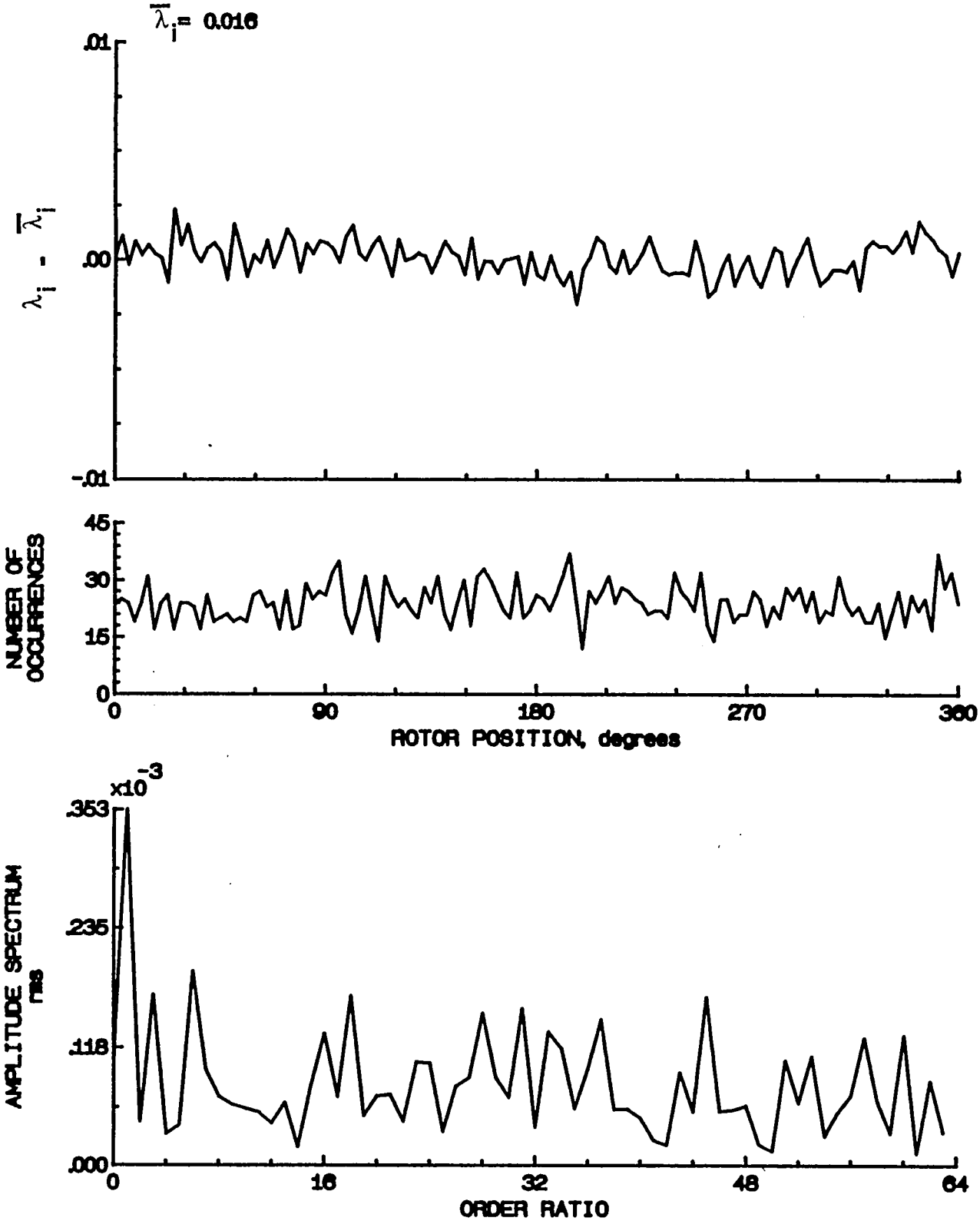


Figure 55.- Induced inflow velocity measured at 60 degrees and r/R of 1.02.



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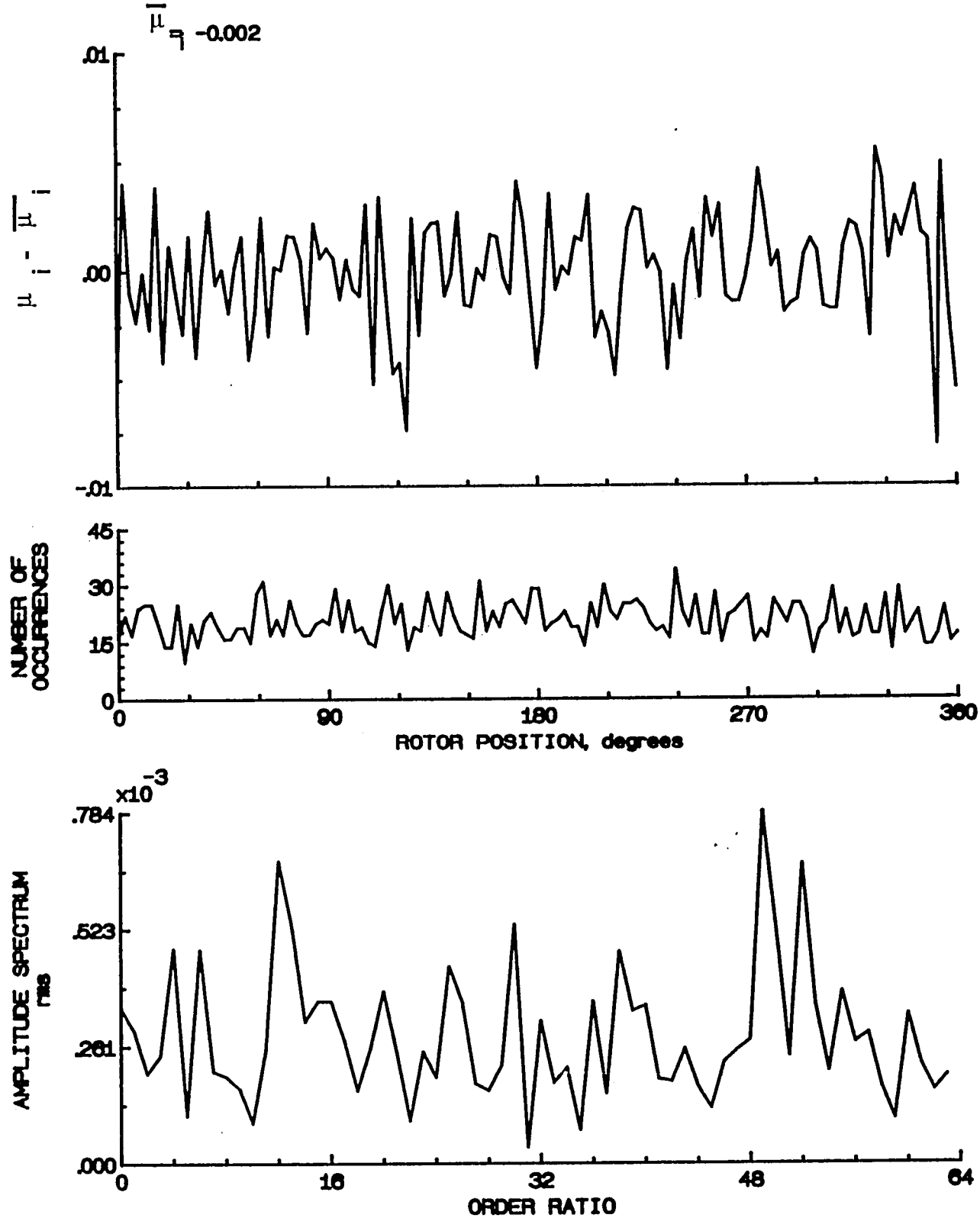
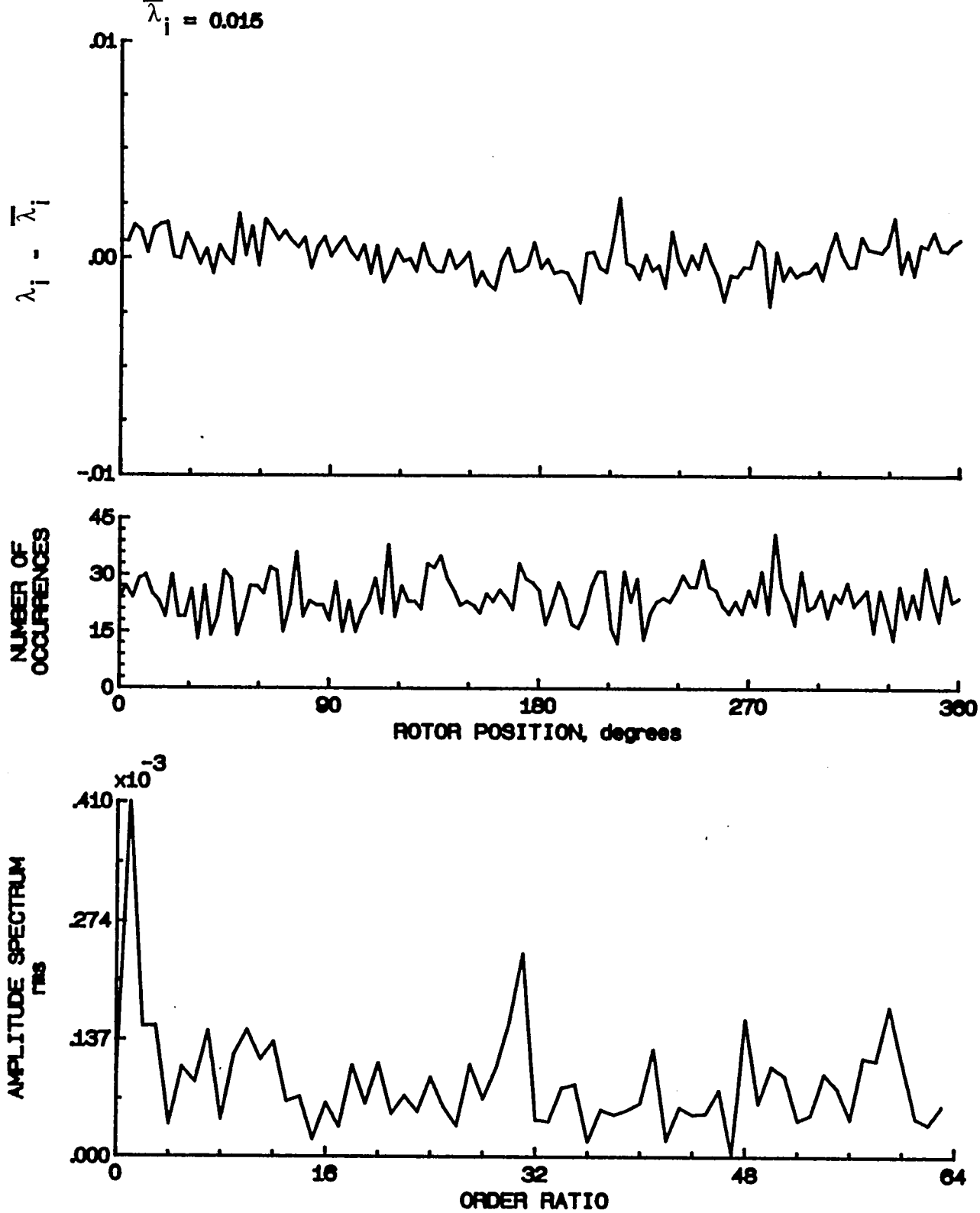


Figure 56.- Induced inflow velocity measured at 60 degrees and r/R of 1.04.



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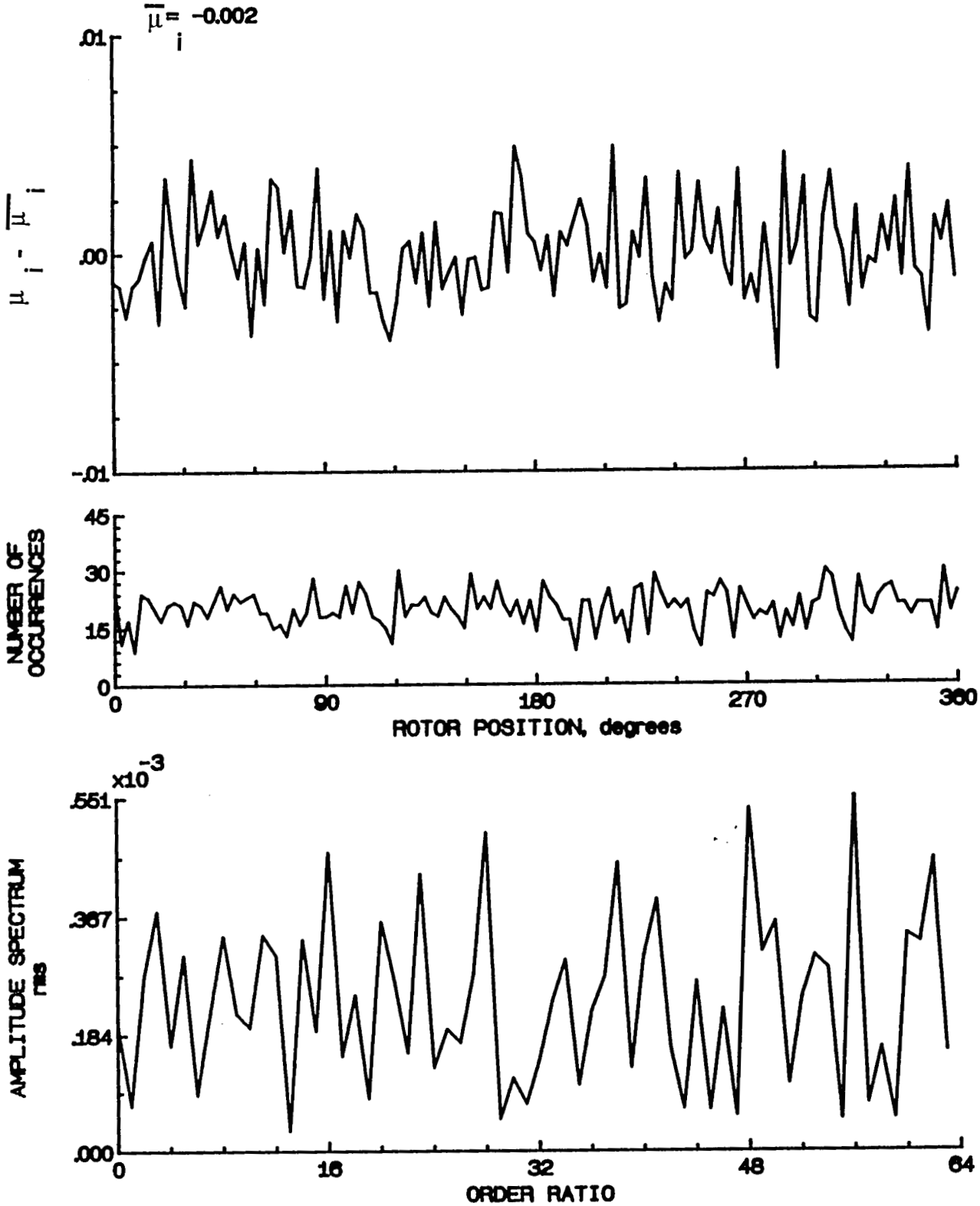
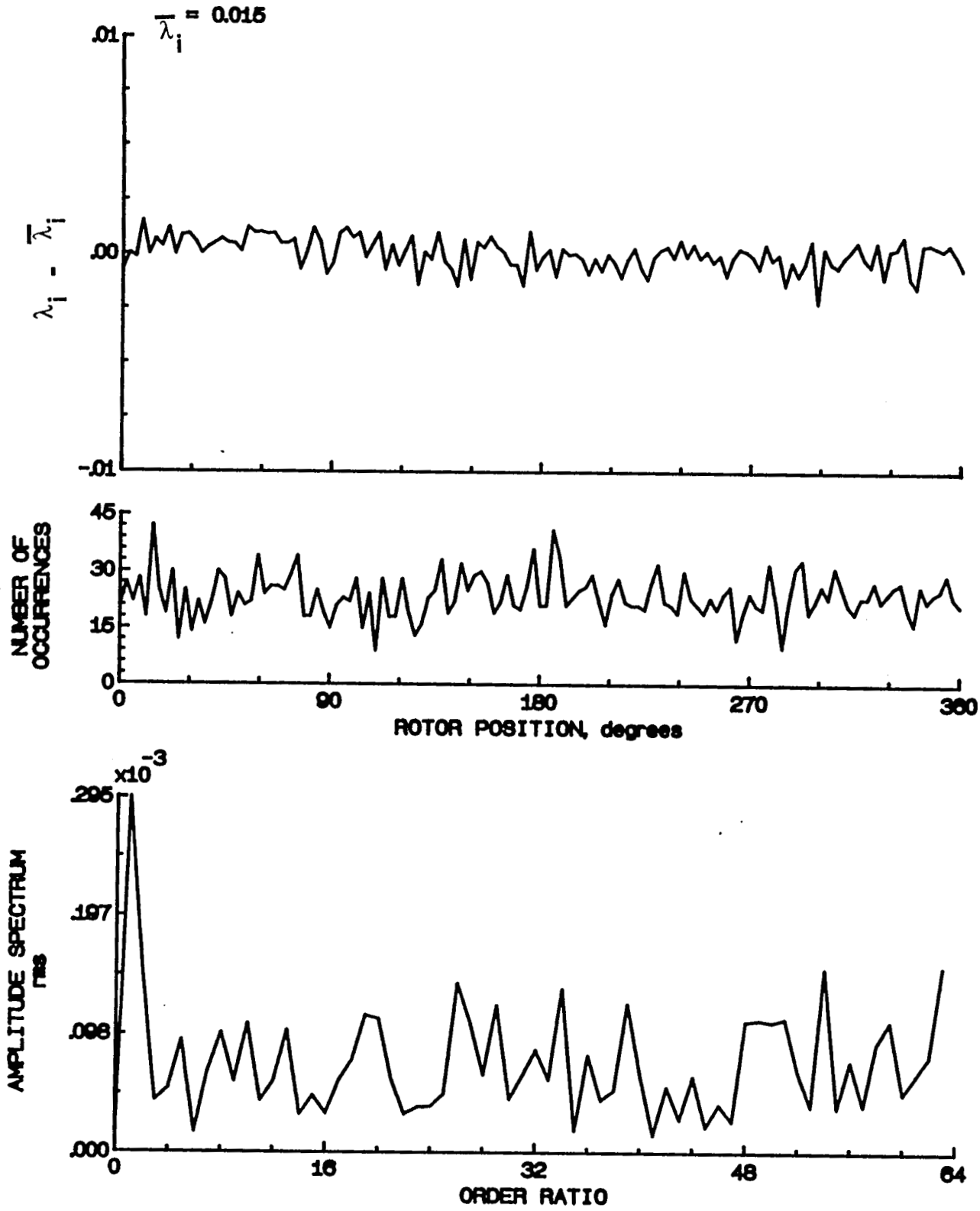


Figure 57.- Induced inflow velocity measured at 60 degrees and r/R of 1.10.



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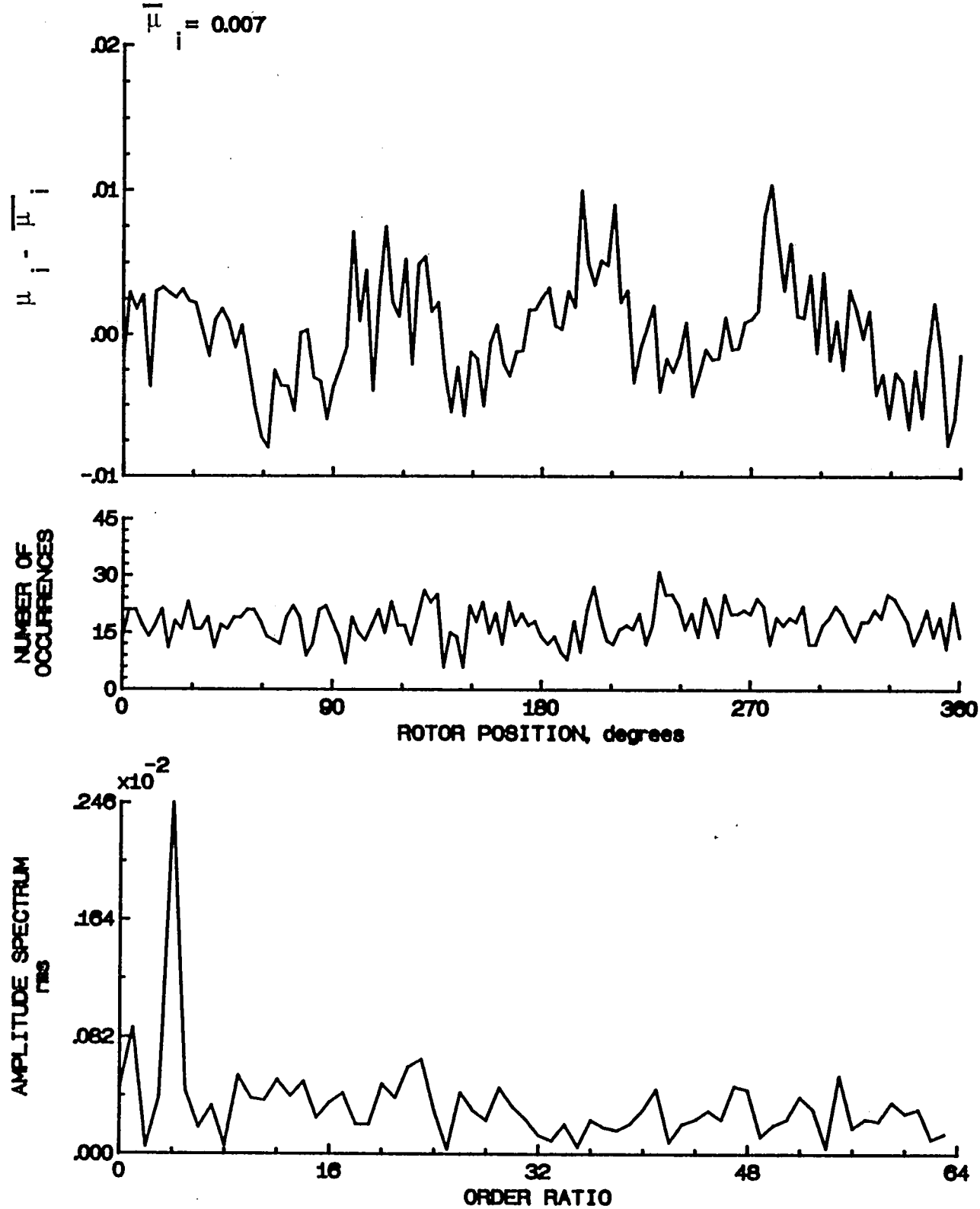
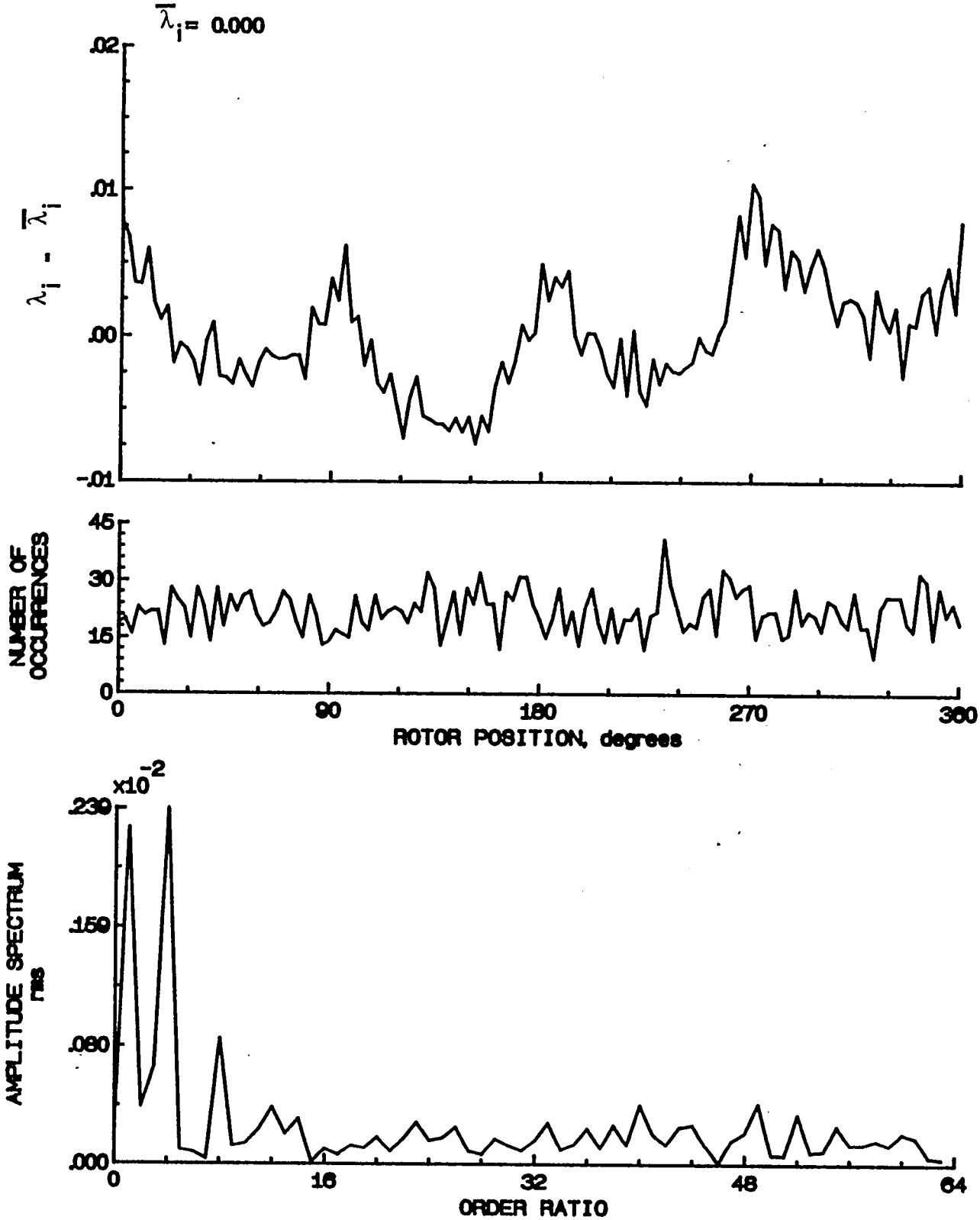


Figure 58.- Induced inflow velocity measured at 90 degrees and r/R of 0.20.



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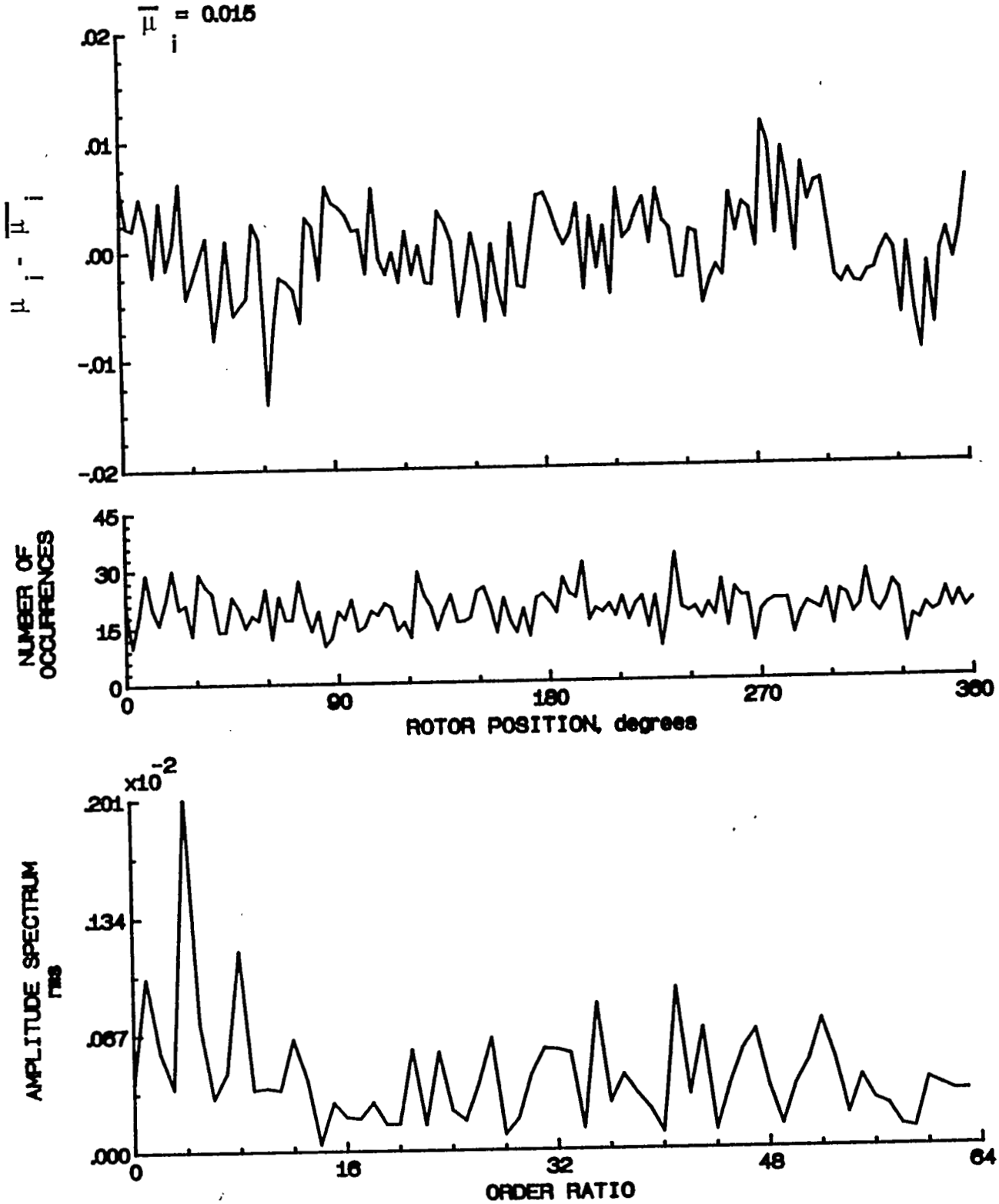
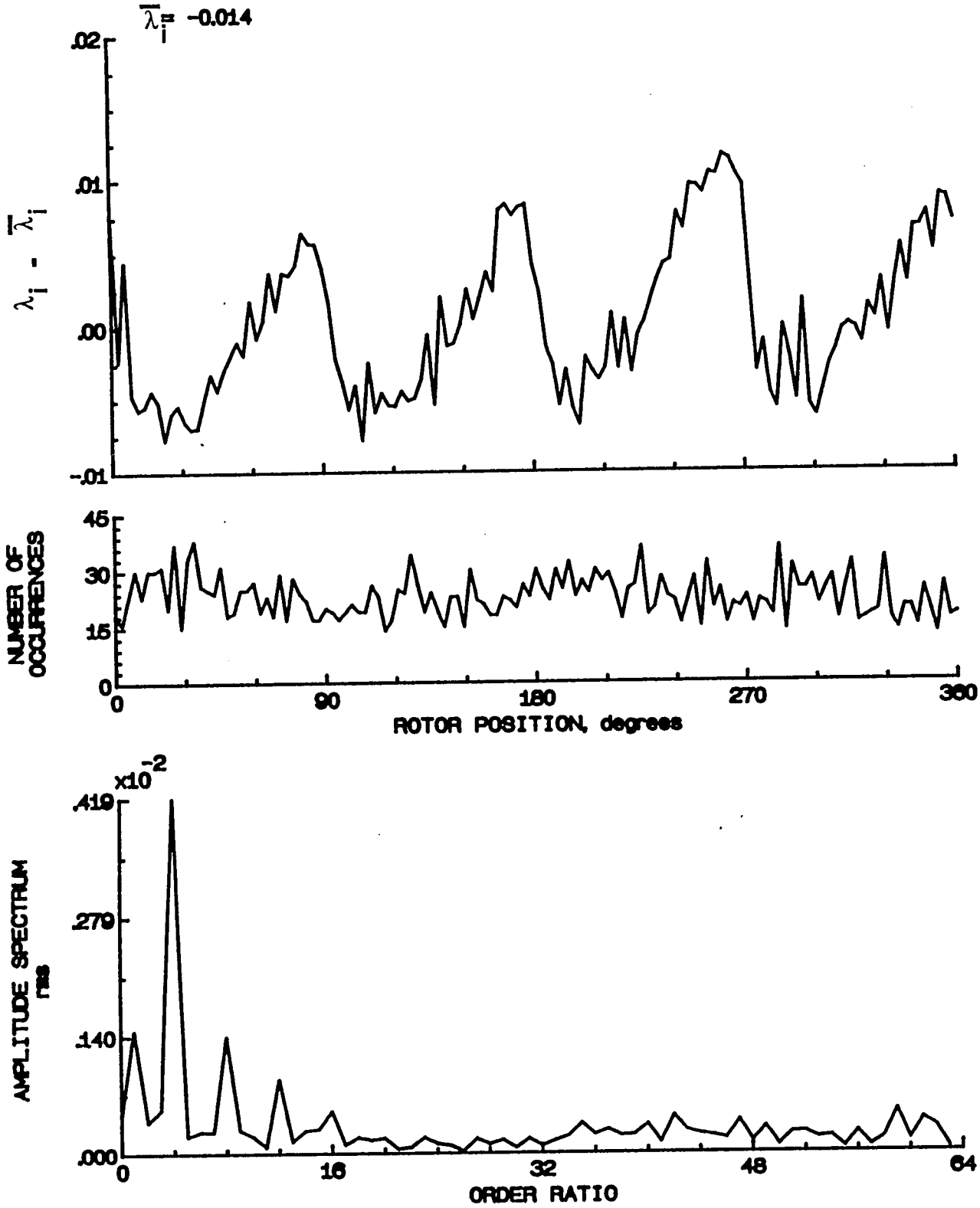


Figure 59.- Induced inflow velocity measured at 90 degrees and r/R of 0.40.



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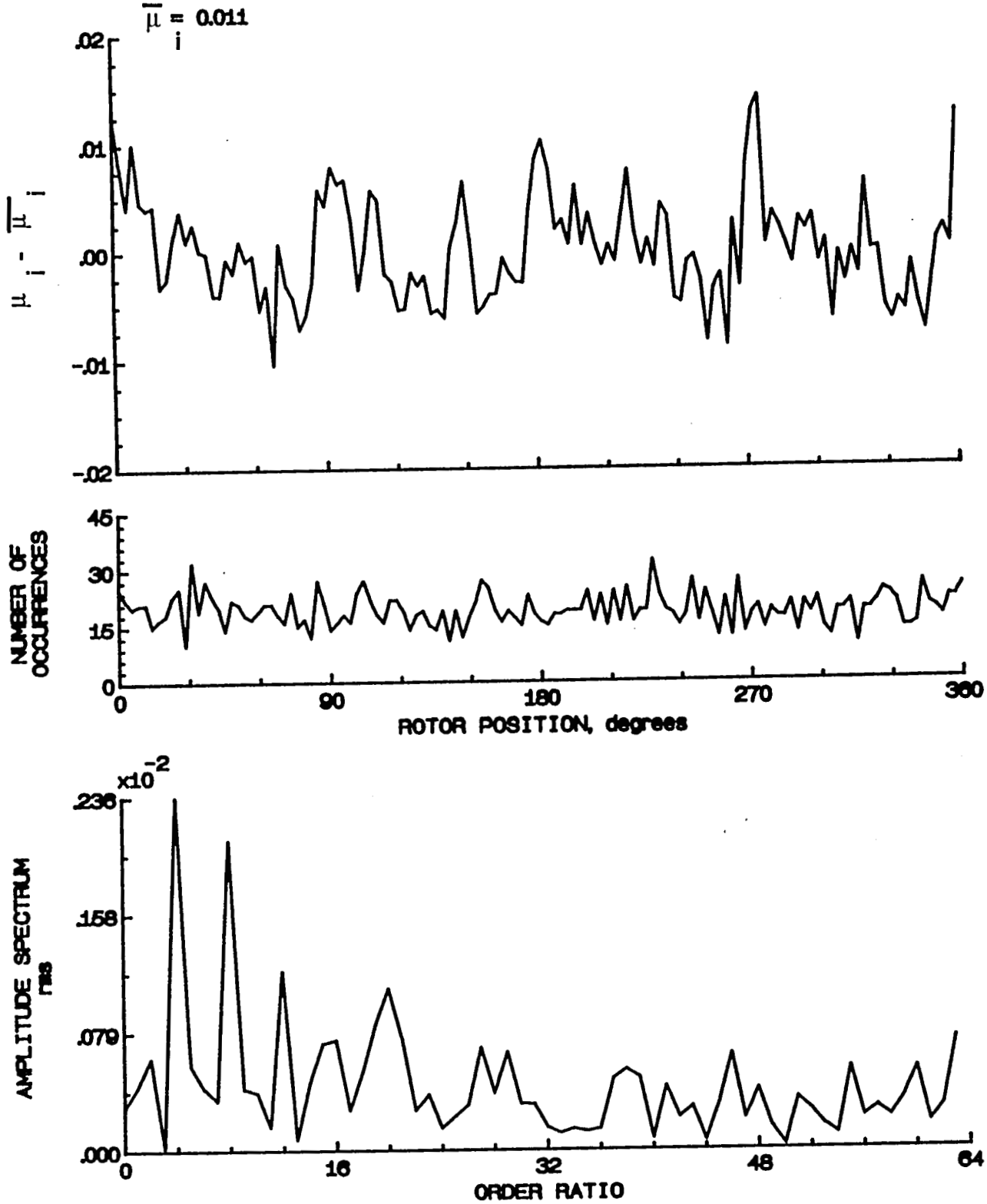
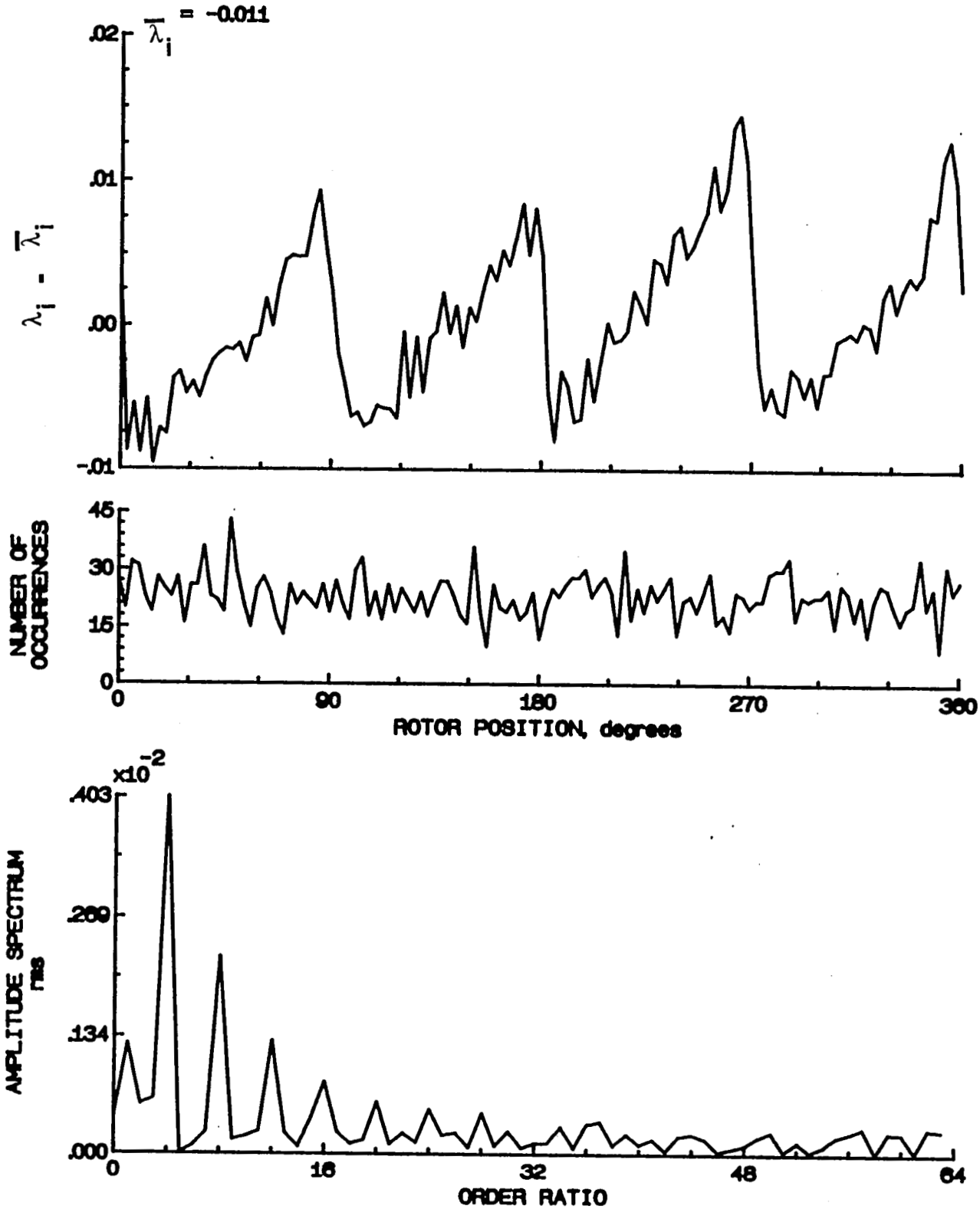


Figure 60.- Induced inflow velocity measured at 90 degrees and r/R of 0.50.



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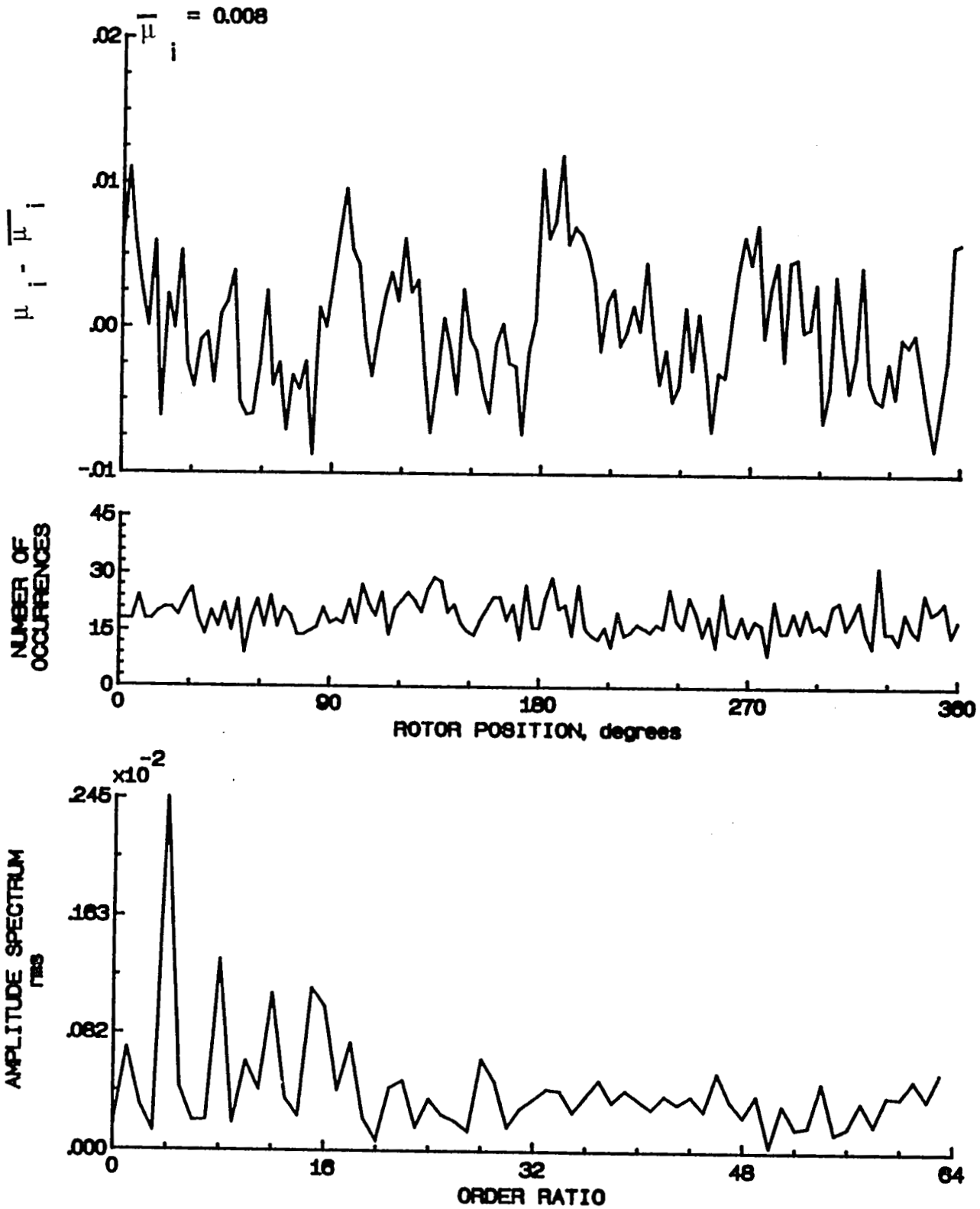


Figure 61.- Induced inflow velocity measured at 90 degrees and r/R of 0.60.

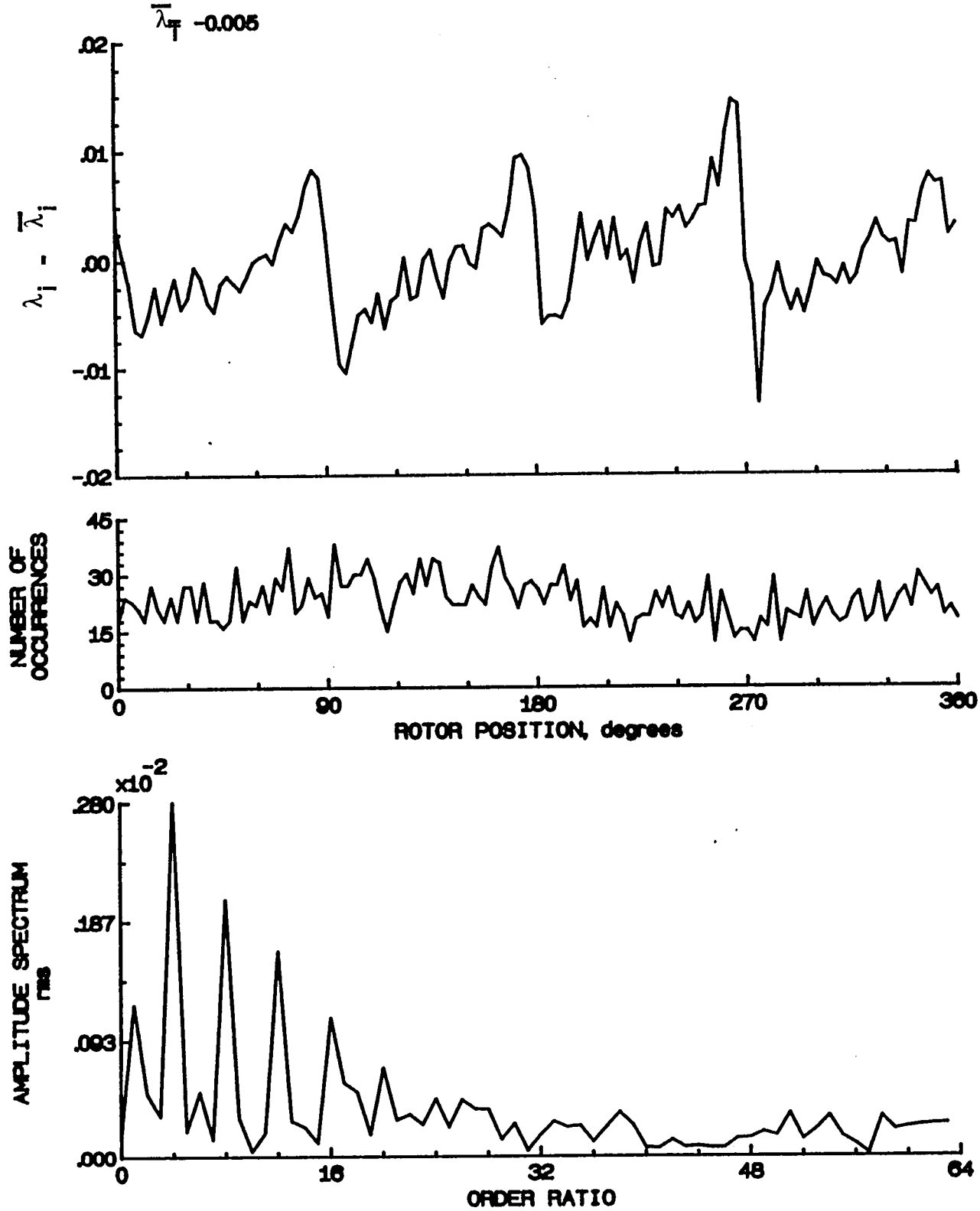


Figure 61.- Concluded.

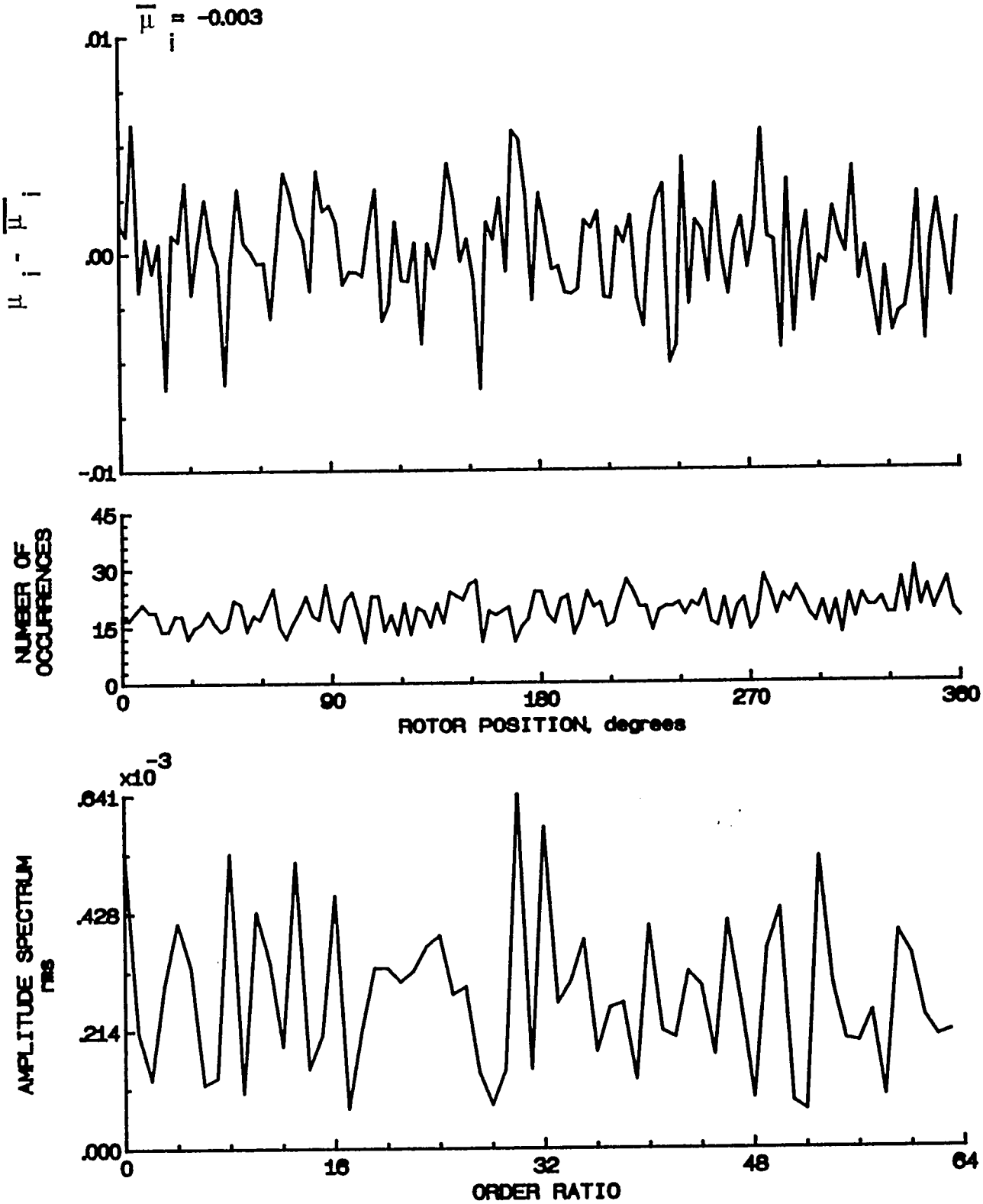
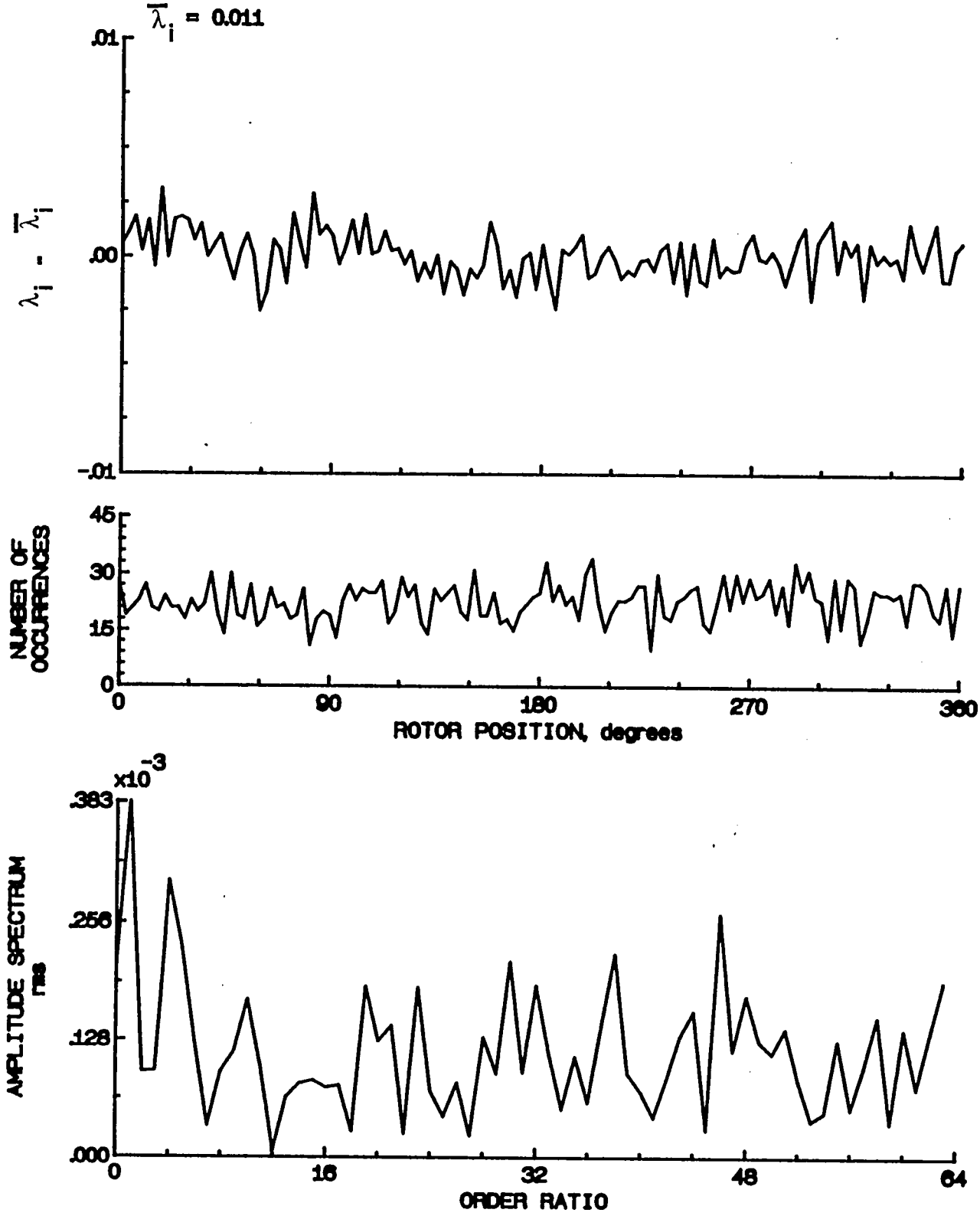


Figure 62.- Induced inflow velocity measured at 90 degrees and r/R of 0.70.



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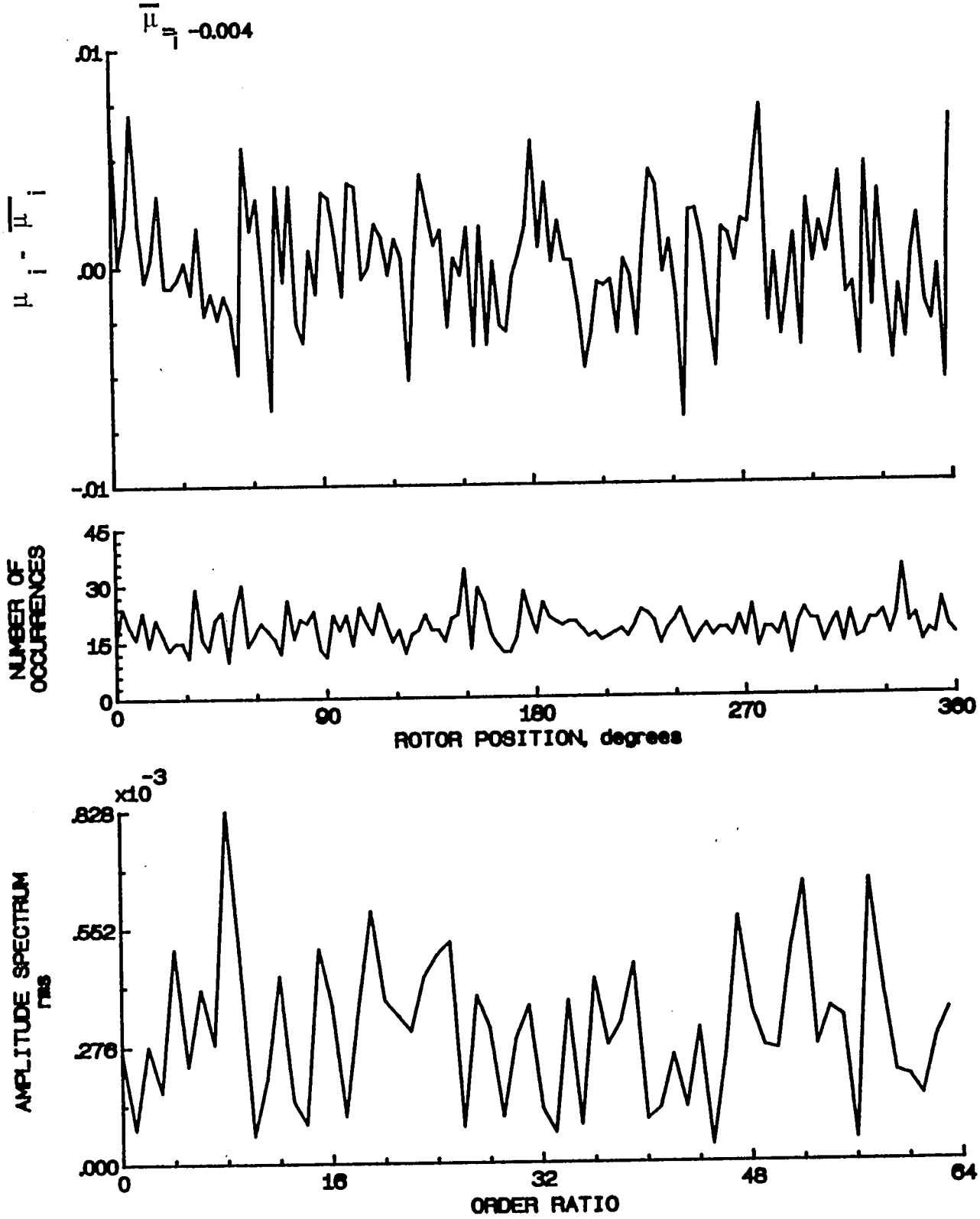
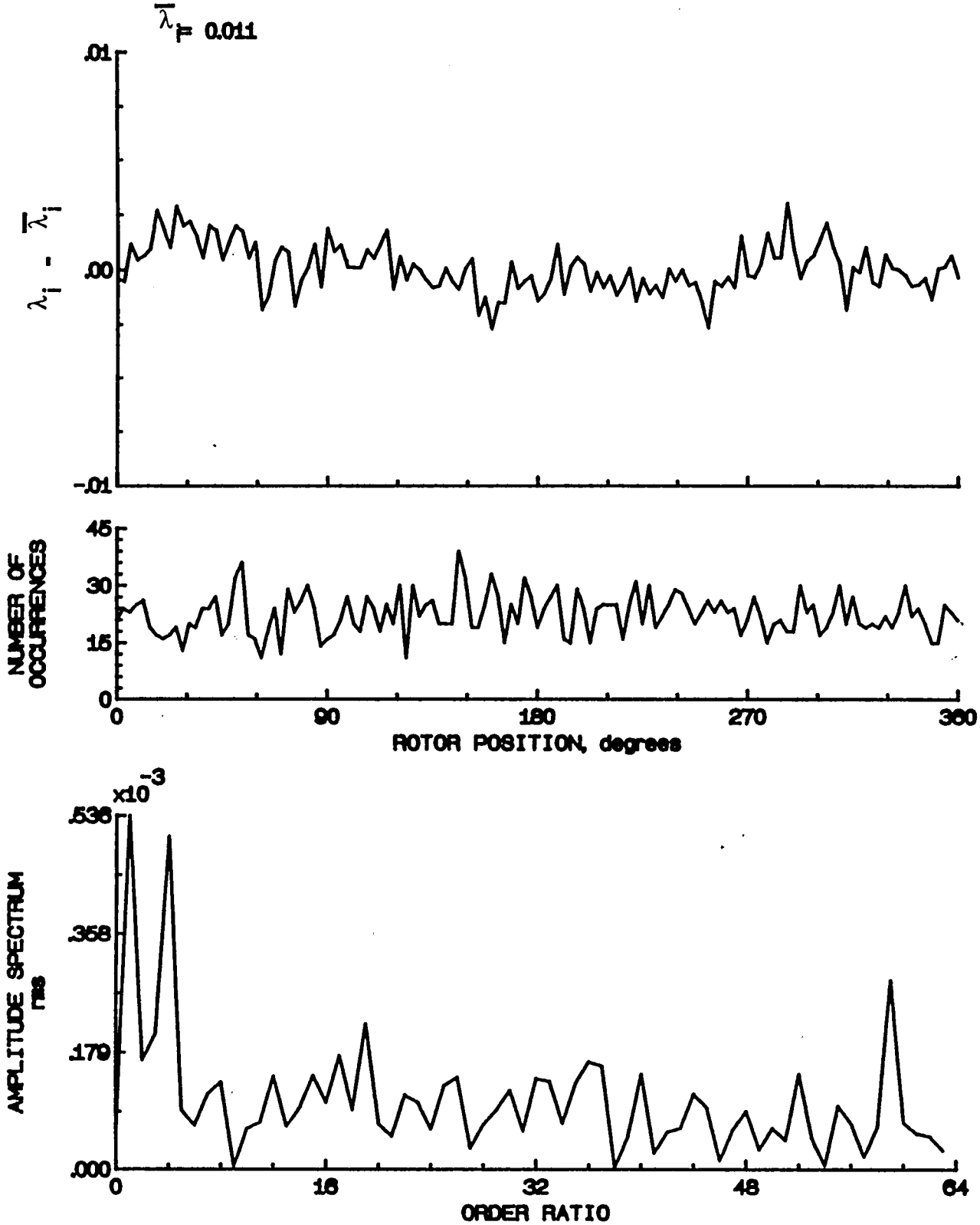


Figure 63.- Induced inflow velocity measured at 90 degrees and r/R of 0.74.



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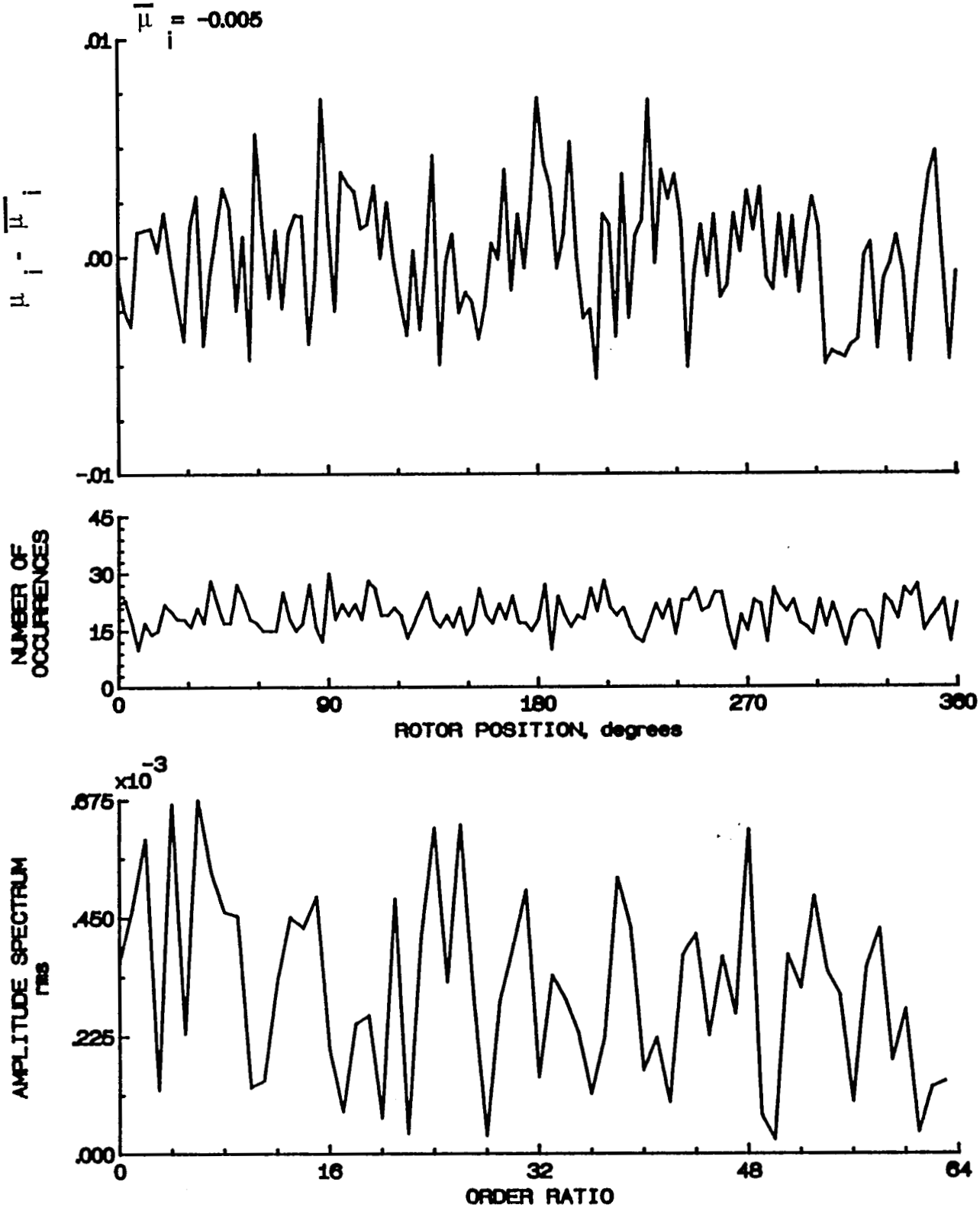
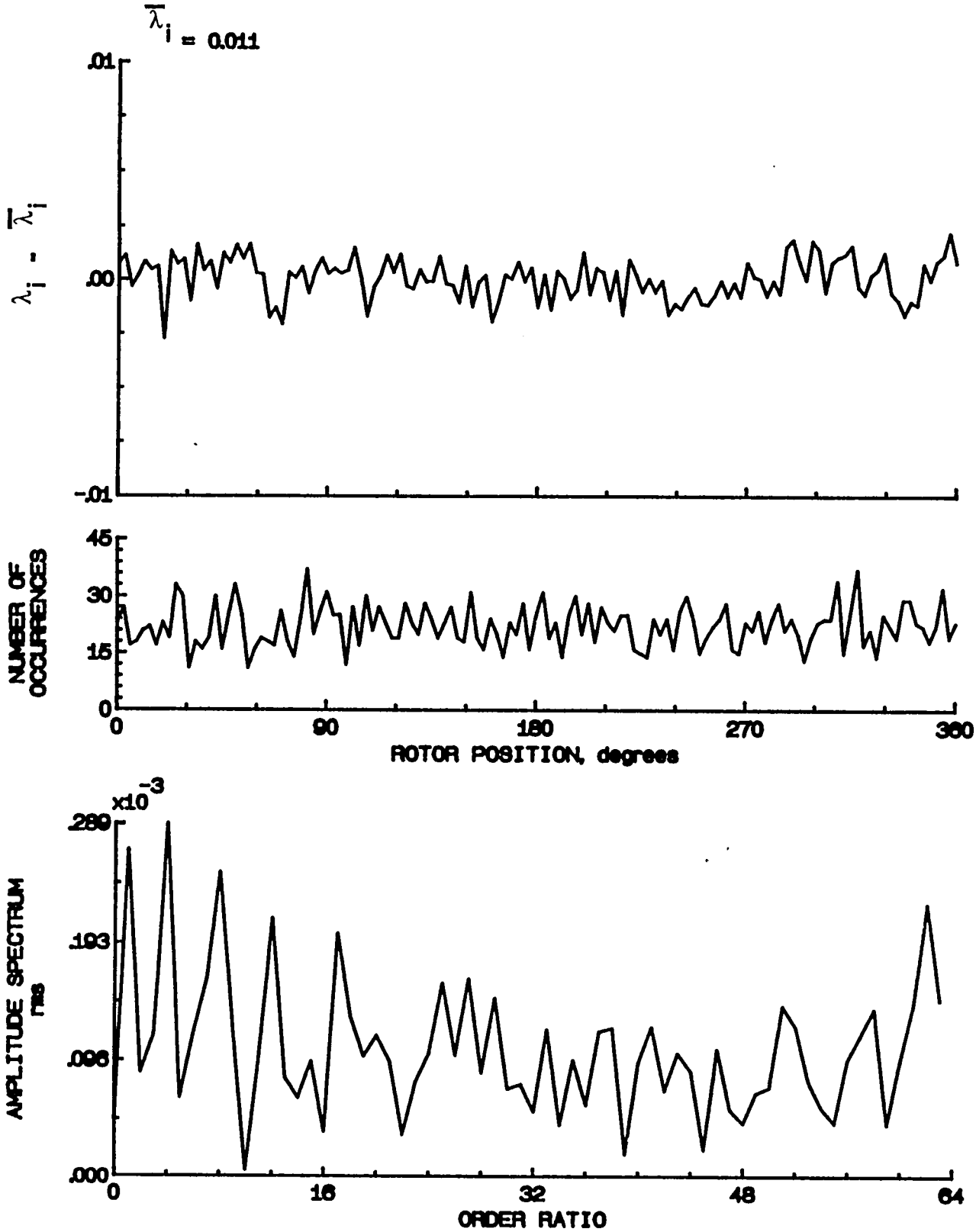


Figure 64.- Induced inflow velocity measured at 90 degrees and r/R of 0.78.



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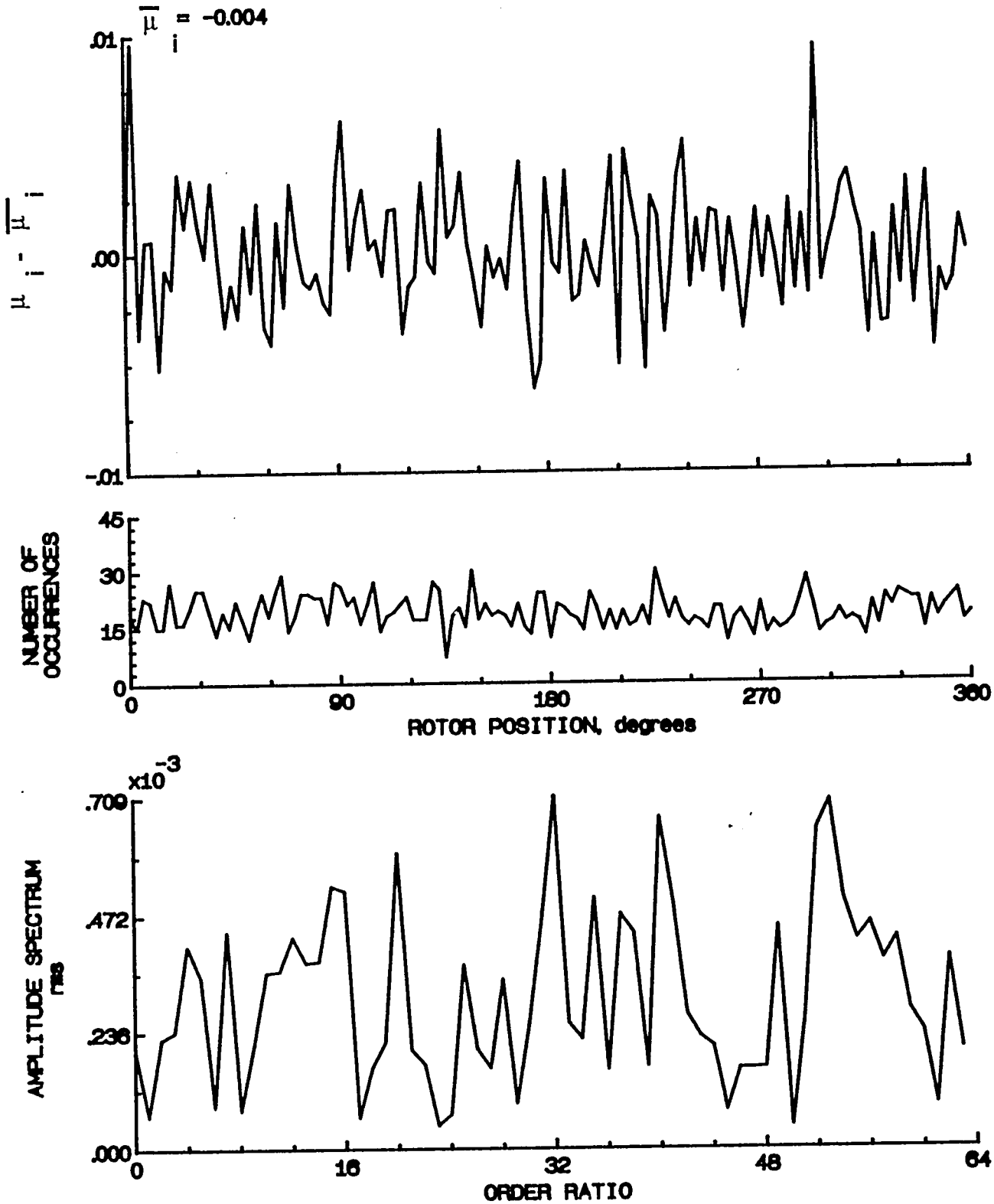
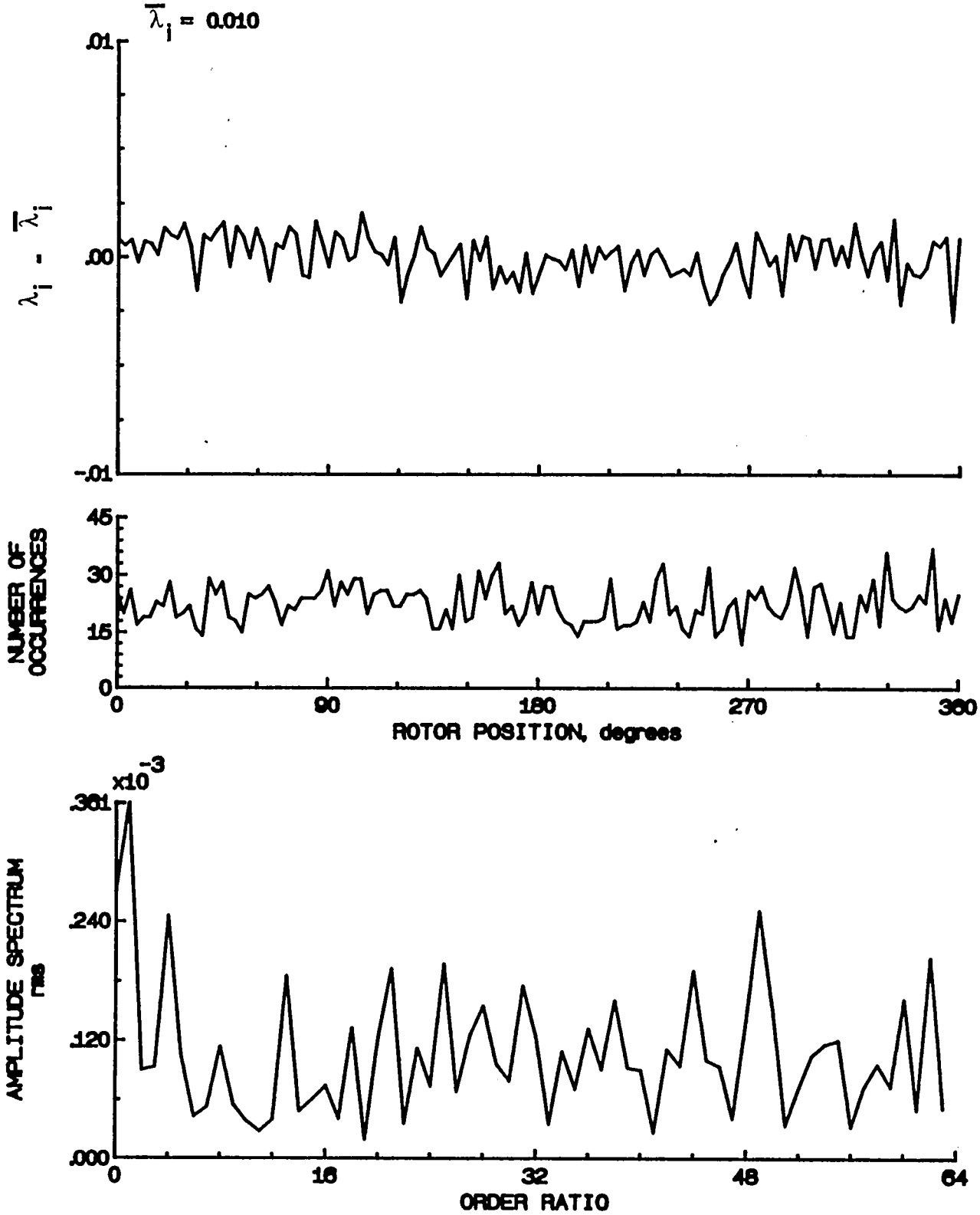


Figure 65.- Induced inflow velocity measured at 90 degrees and r/R of 0.82.



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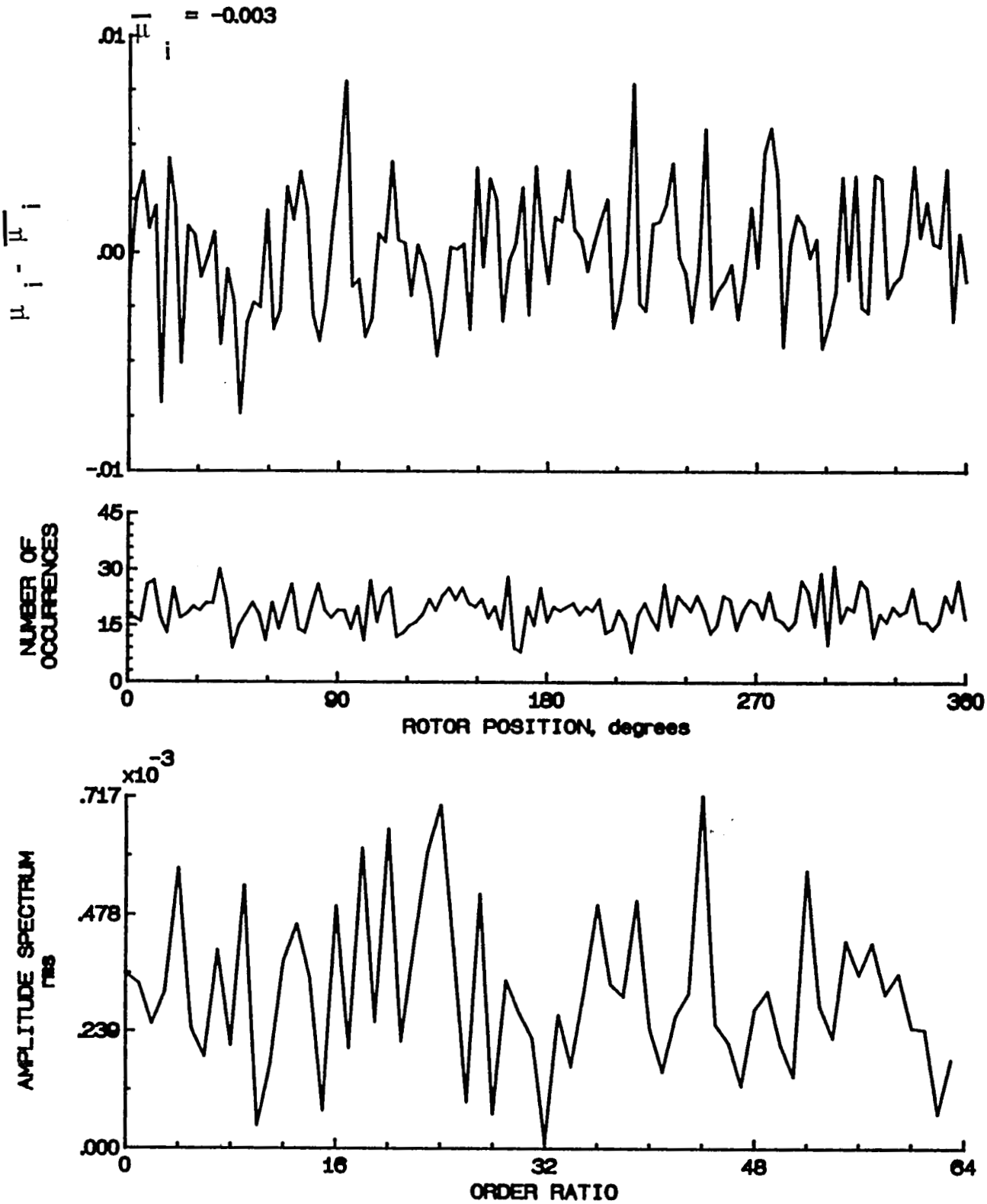
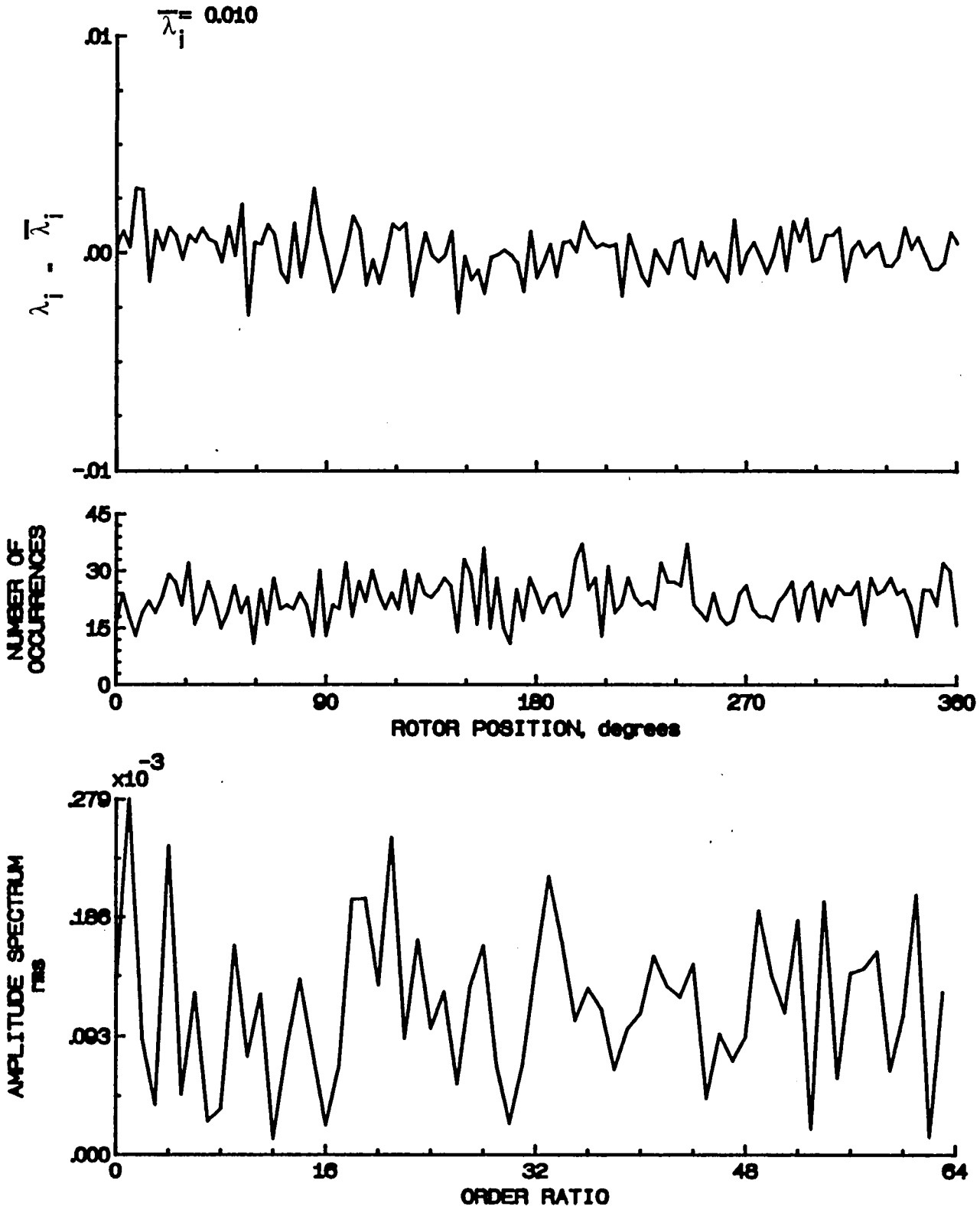


Figure 66.- Induced inflow velocity measured at 90 degrees and r/R of 0.86.



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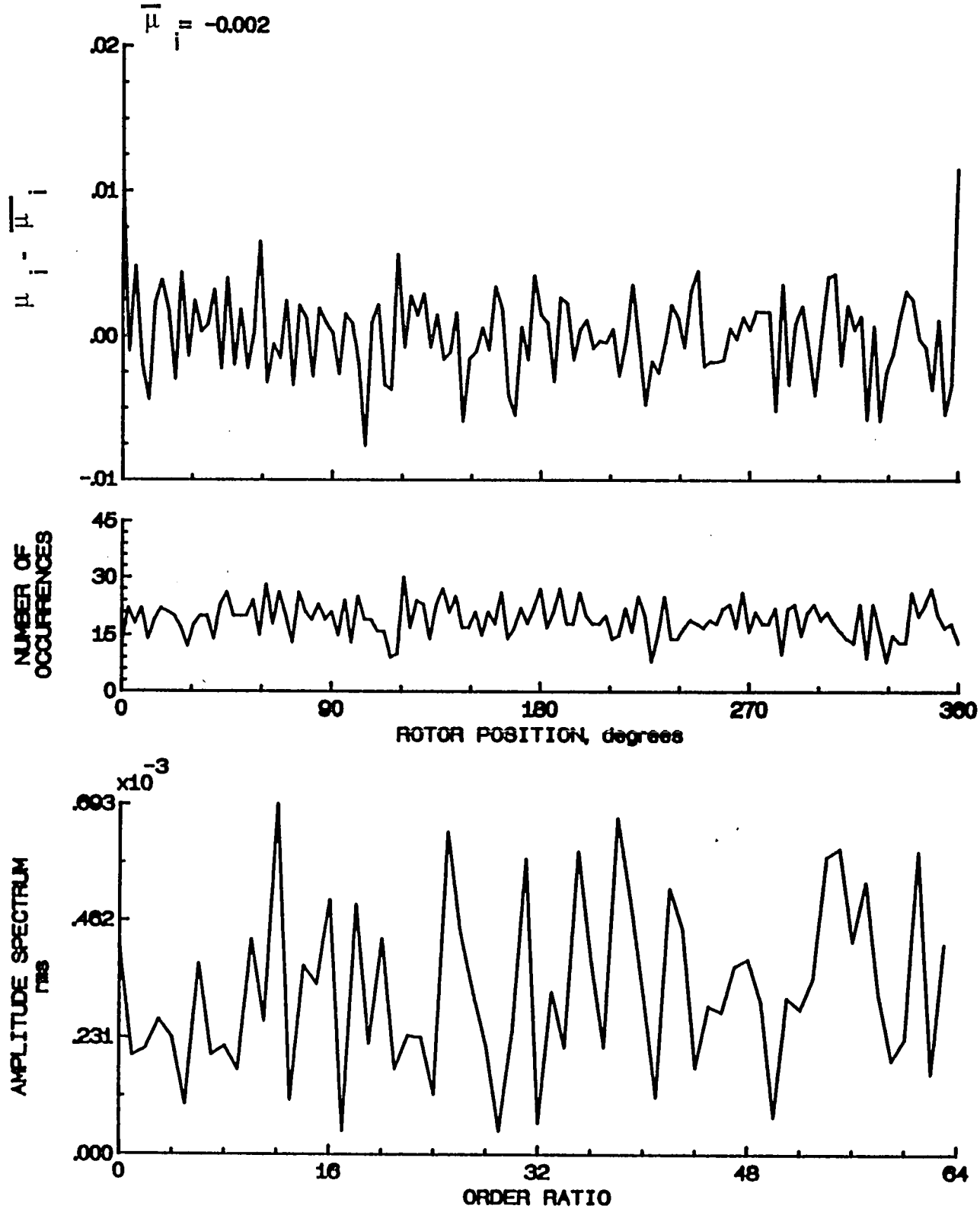
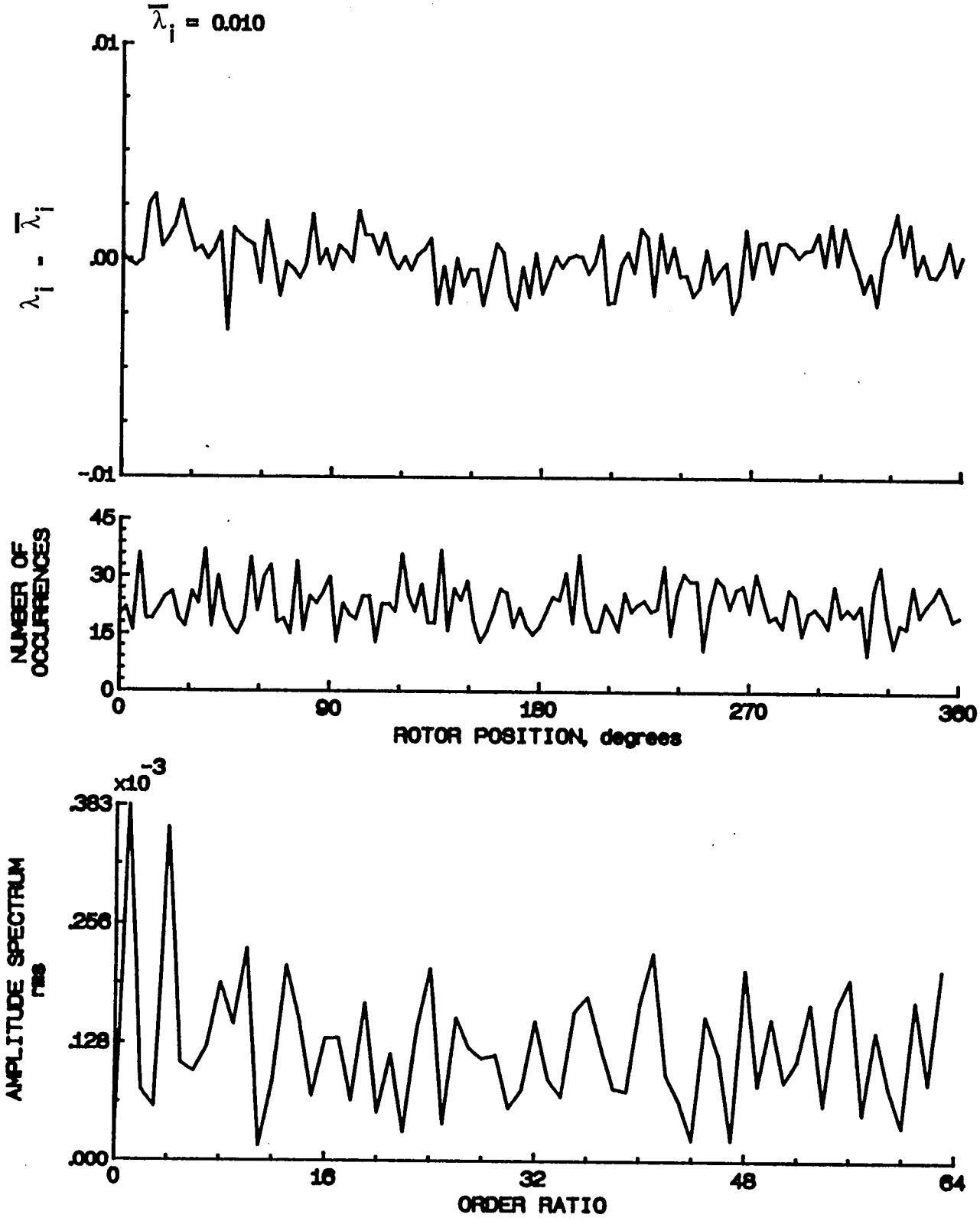


Figure 67.- Induced inflow velocity measured at 90 degrees and r/R of 0.90.



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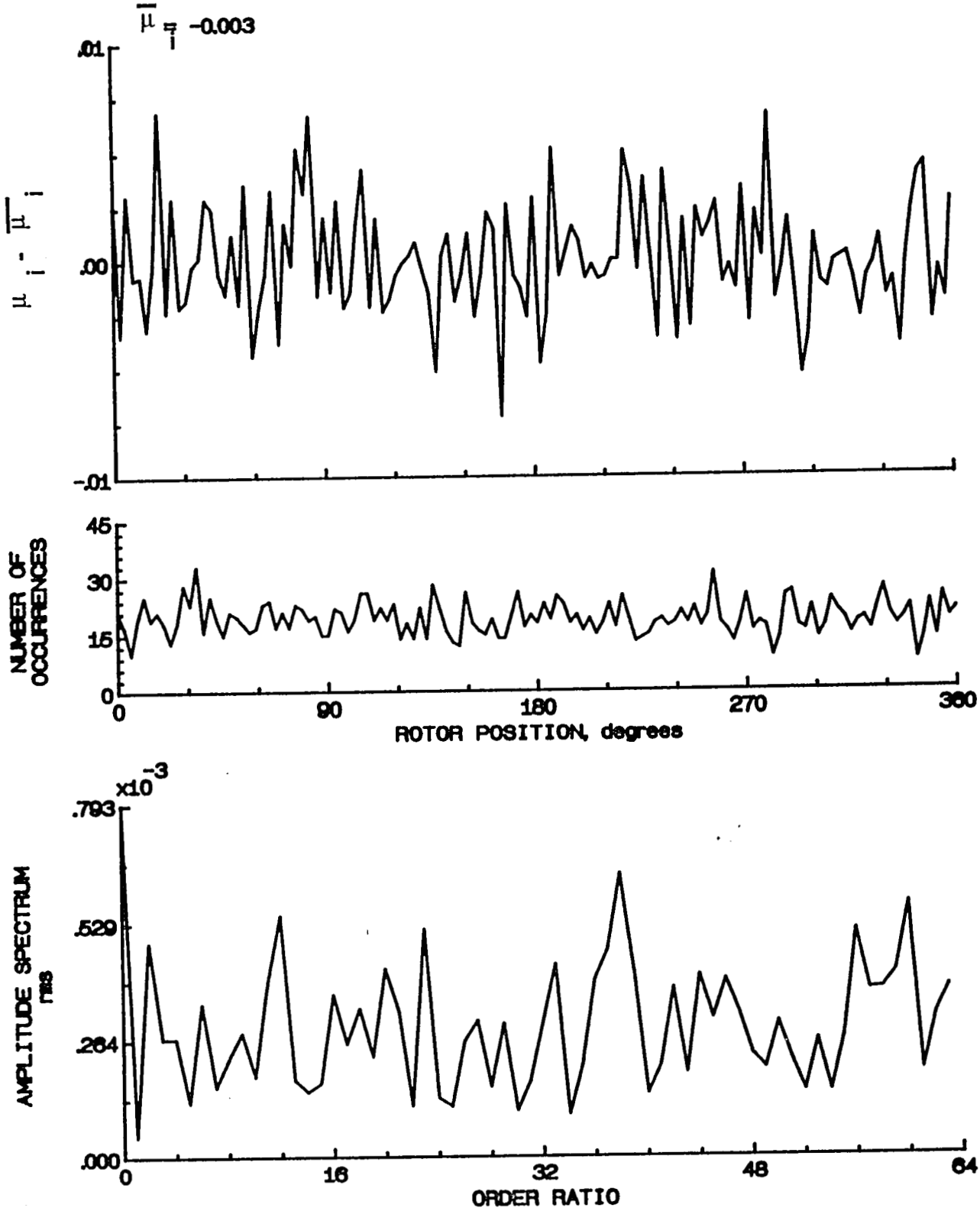
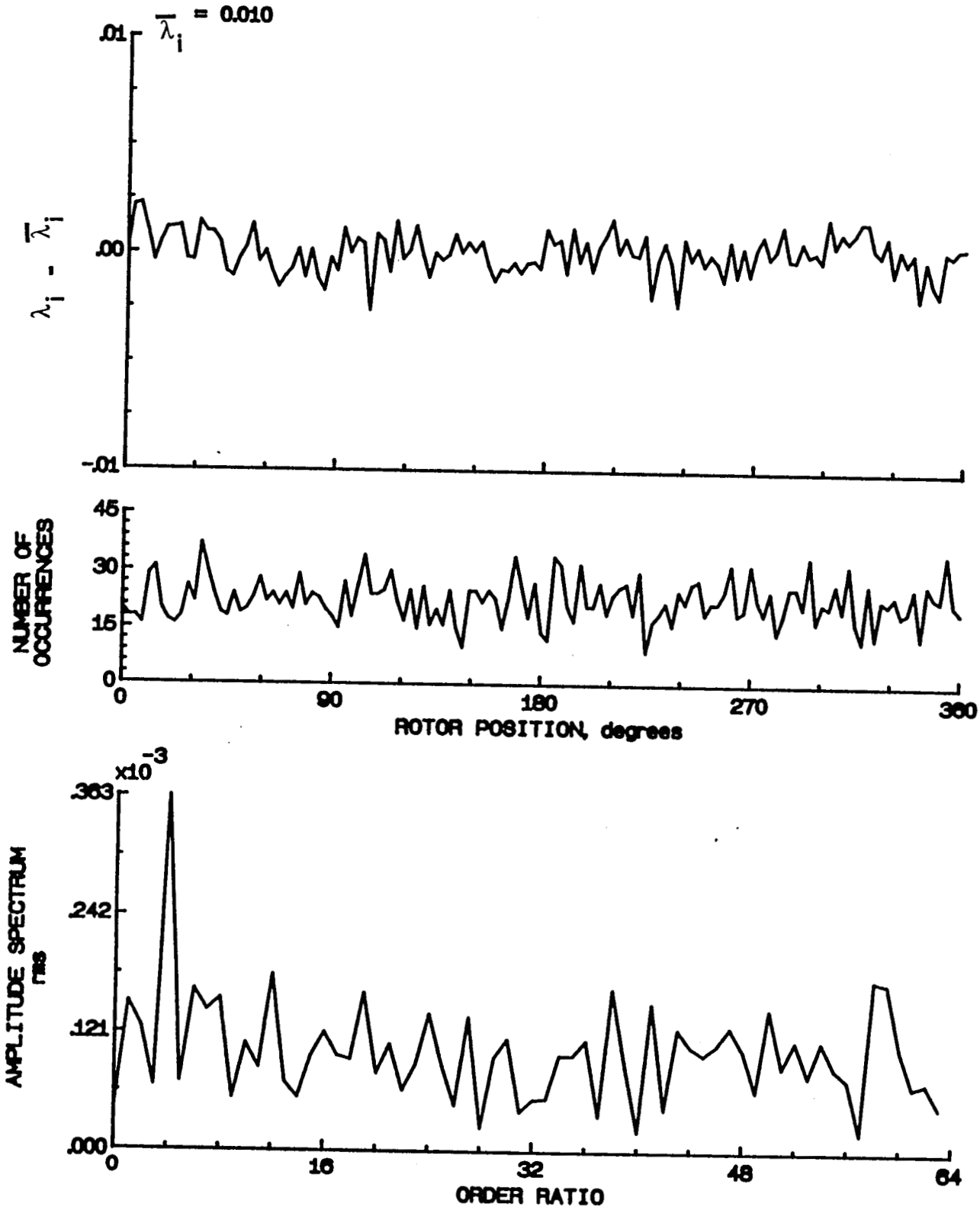


Figure 68.- Induced inflow velocity measured at 90 degrees and r/R of 0.94.



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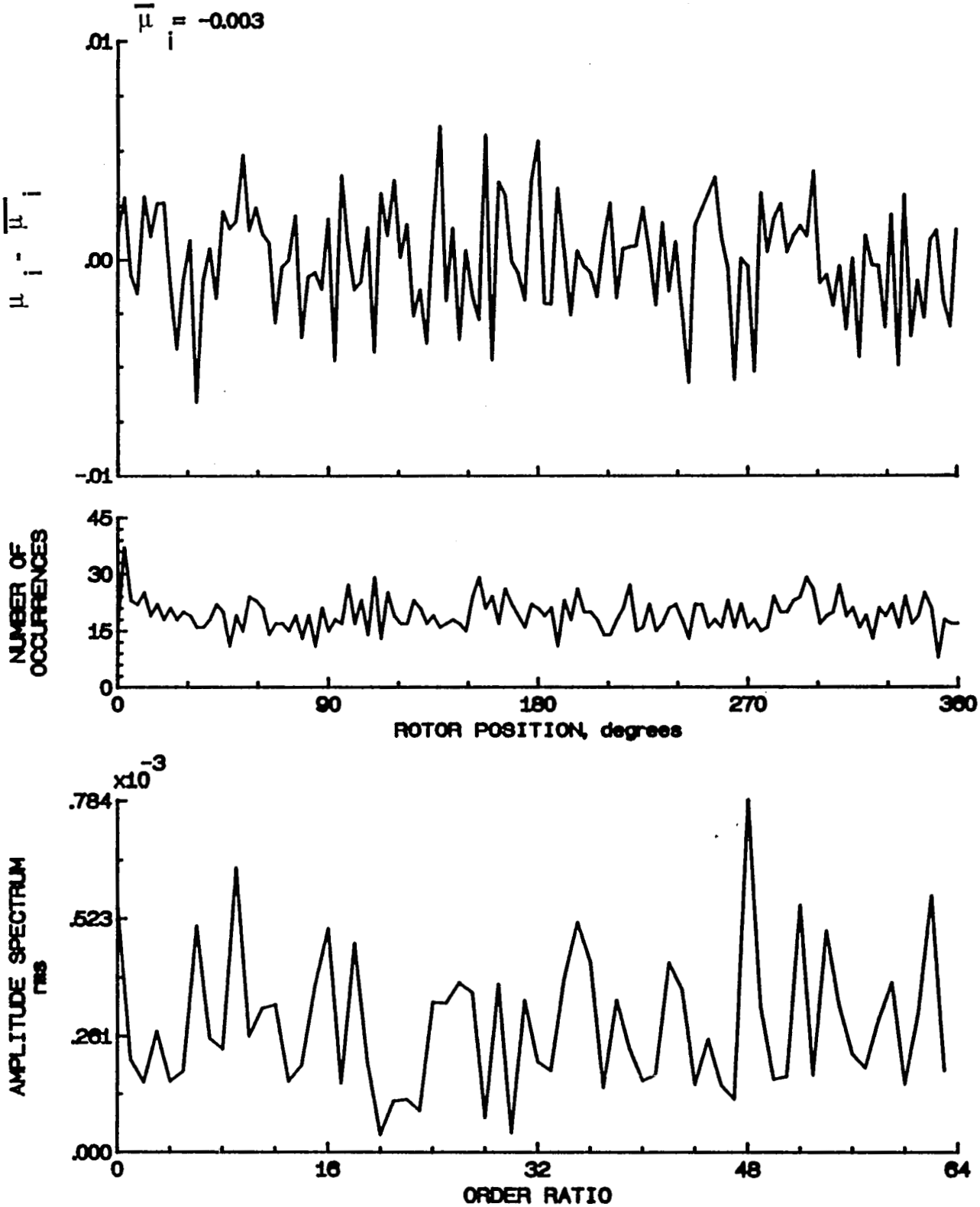
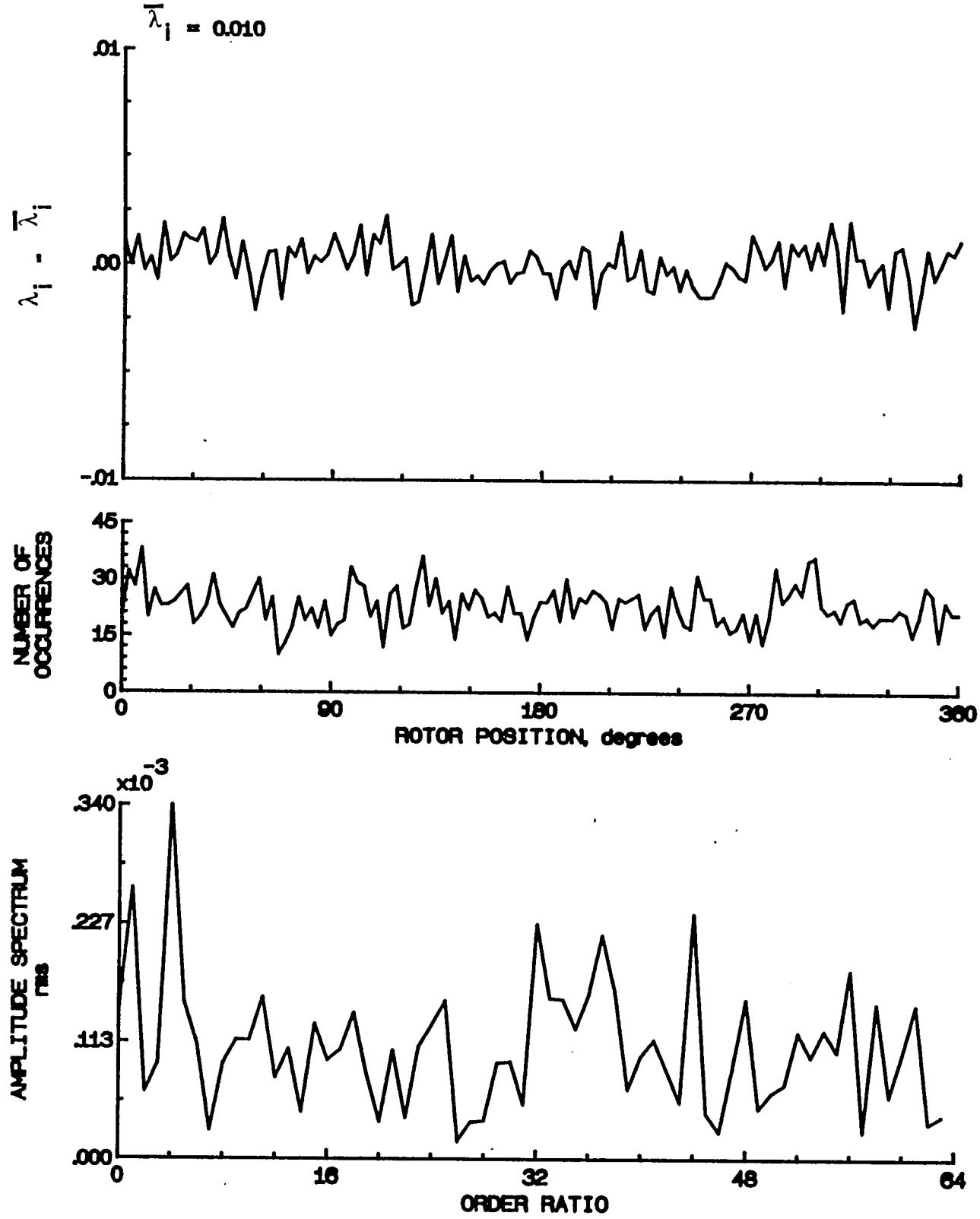


Figure 69.- Induced inflow velocity measured at 90 degrees and r/R of 0.98.



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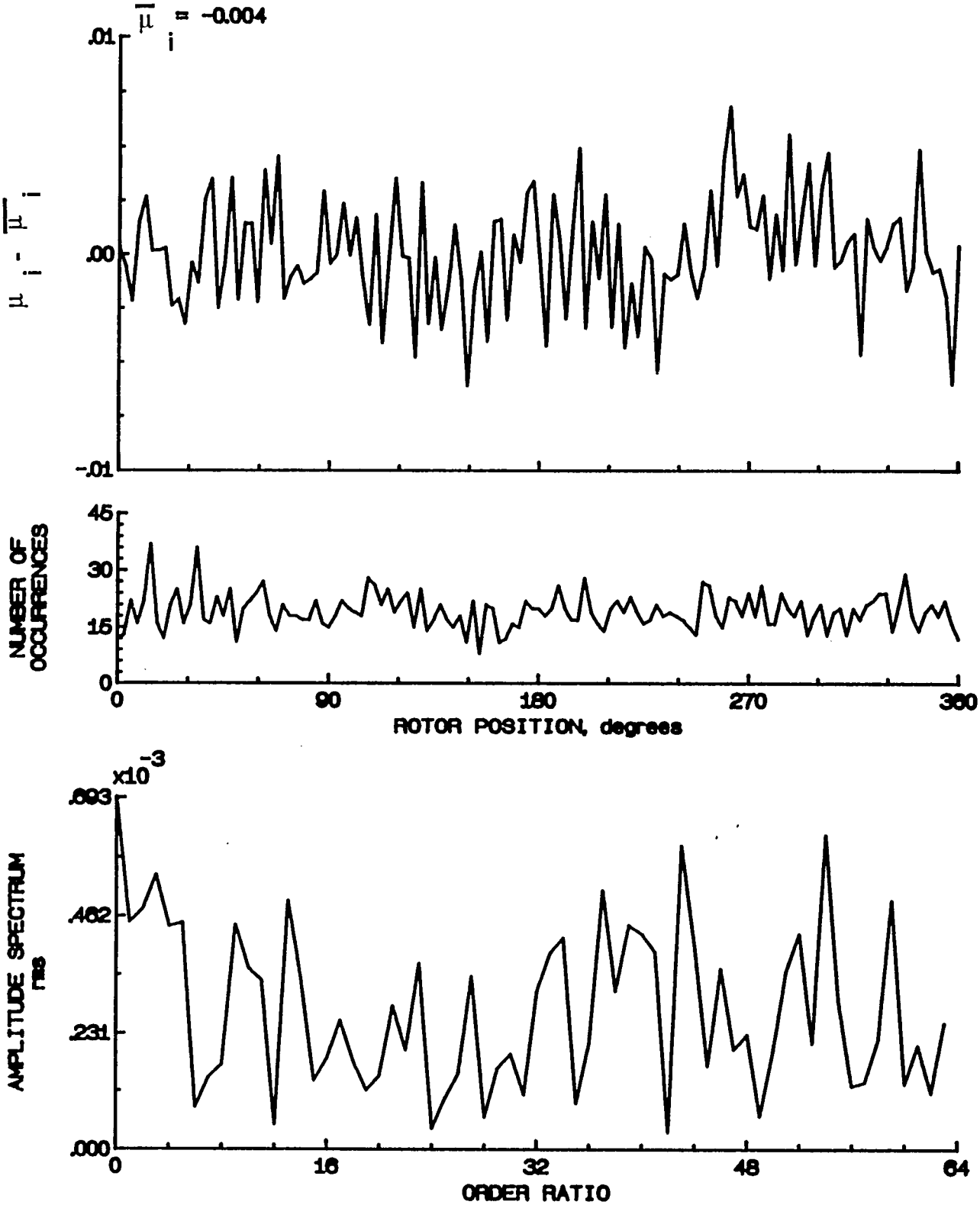
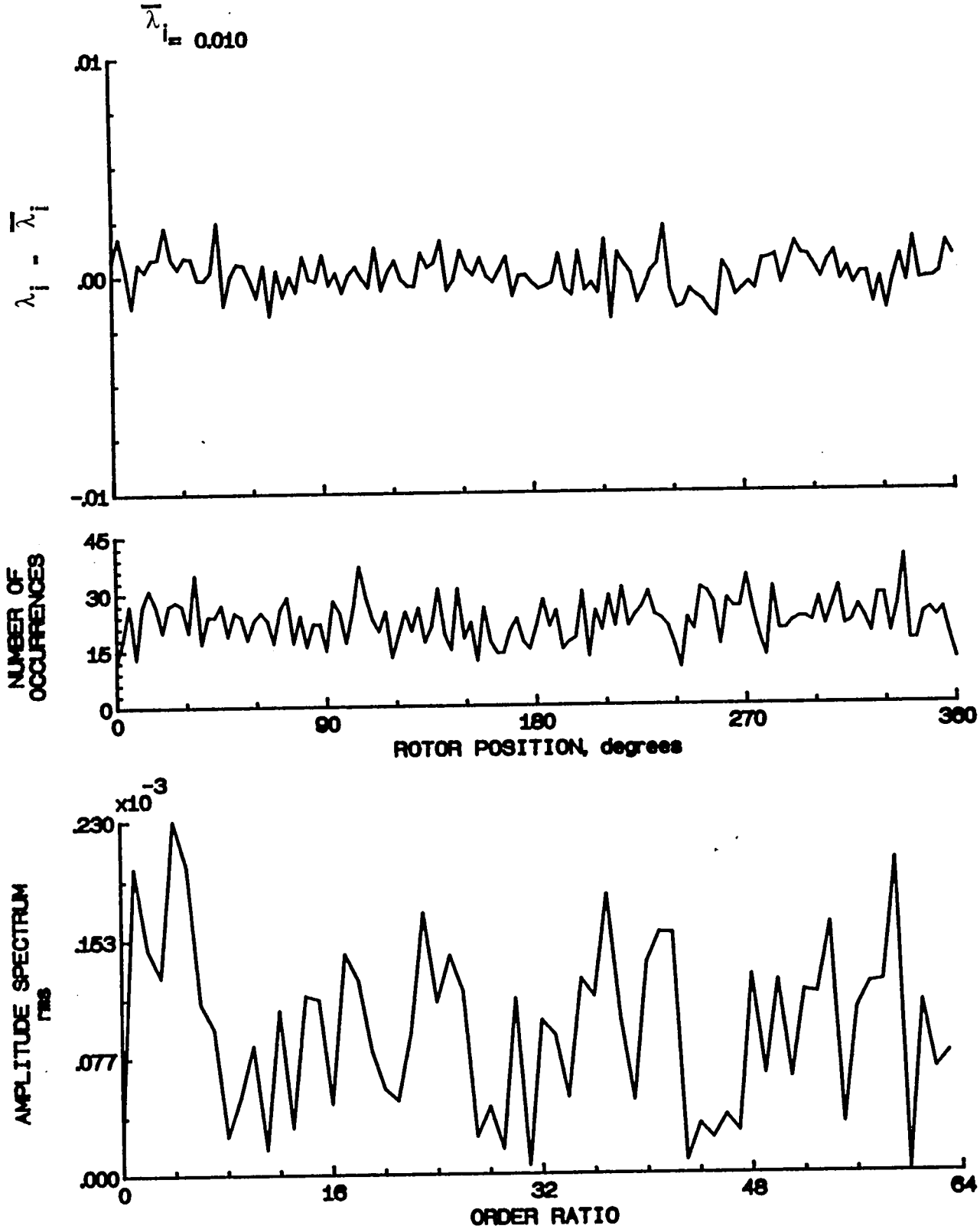


Figure 70.- Induced inflow velocity measured at 90 degrees and r/R of 1.02.



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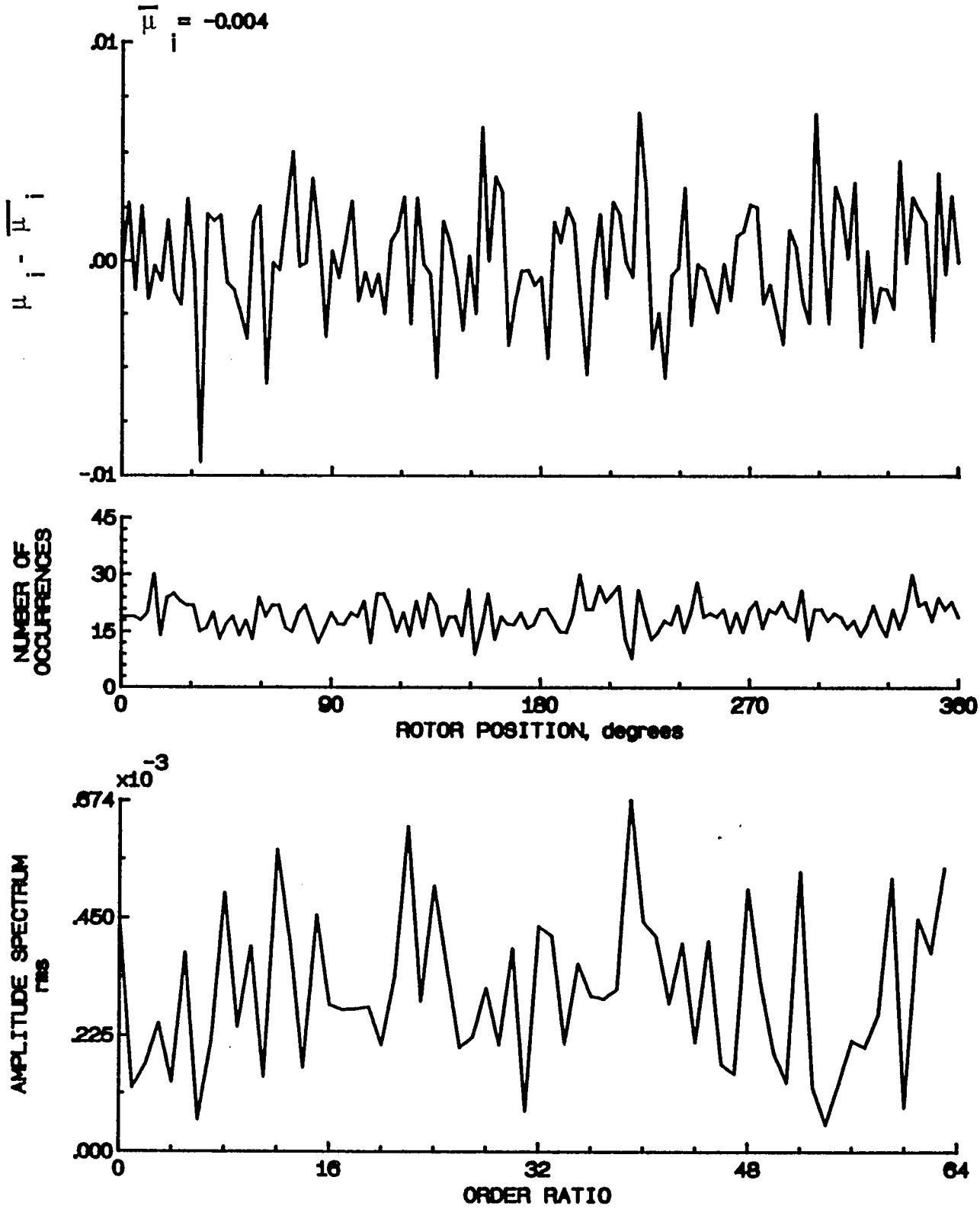
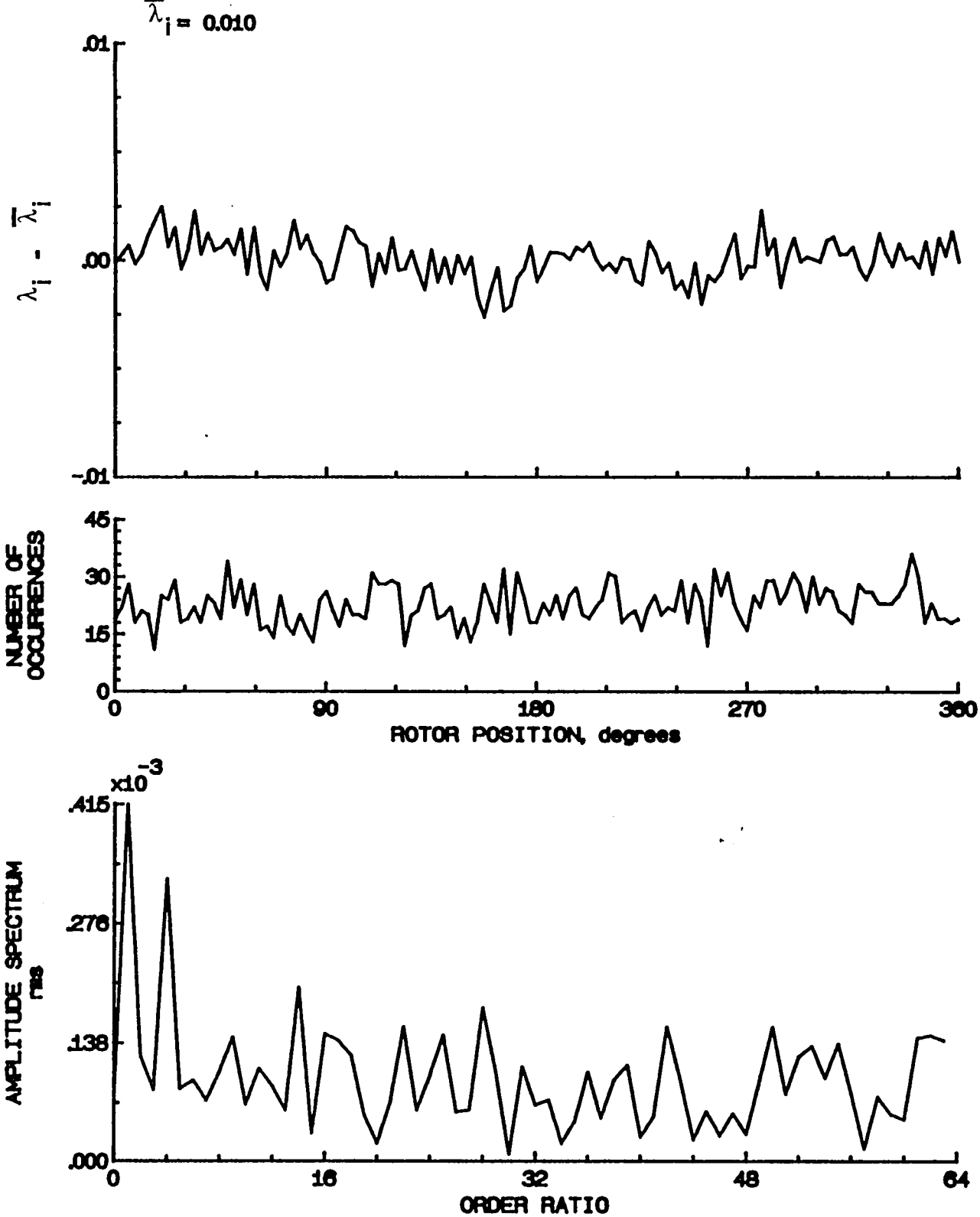


Figure 71.- Induced inflow velocity measured at 90 degrees and r/R of 1.04.



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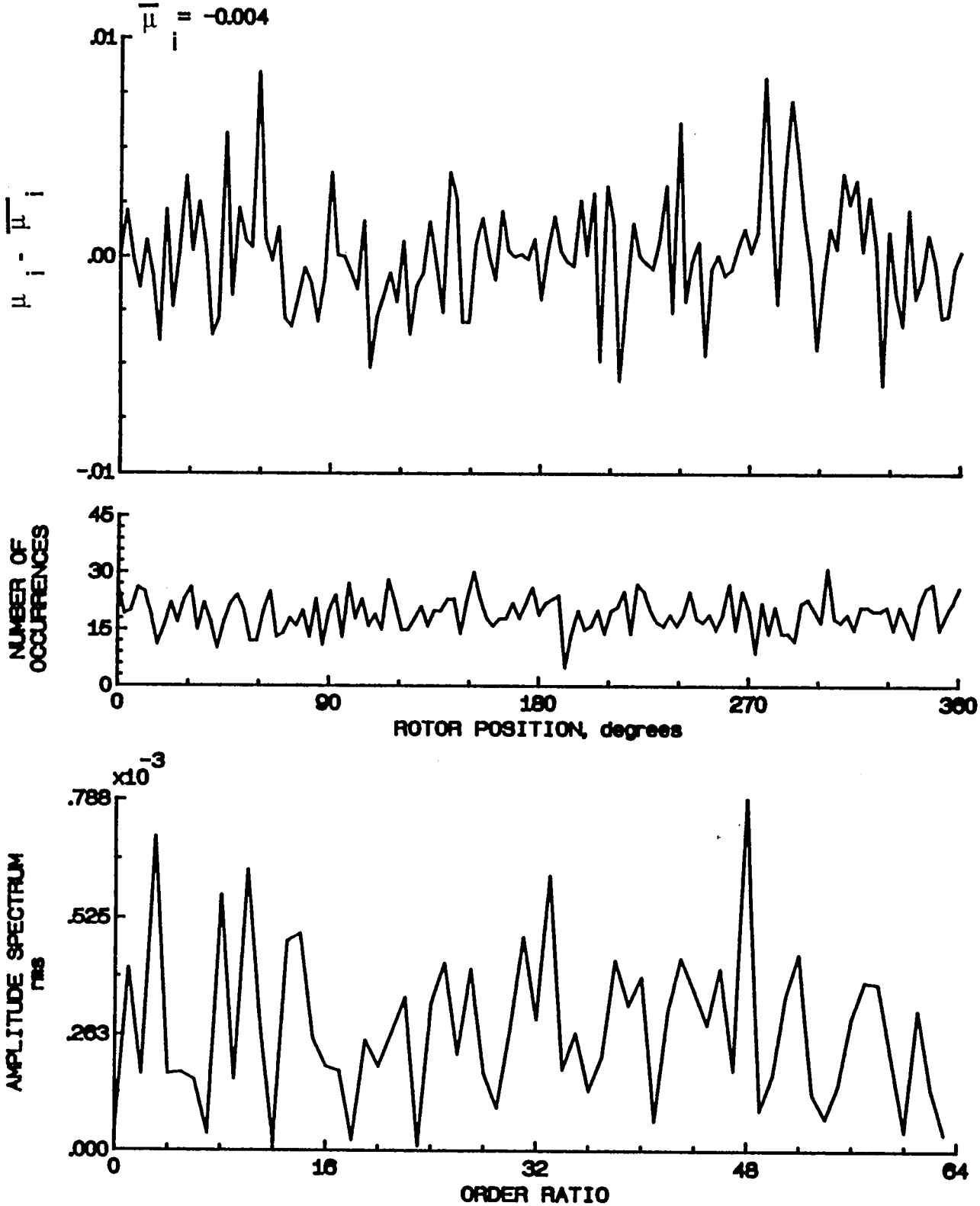
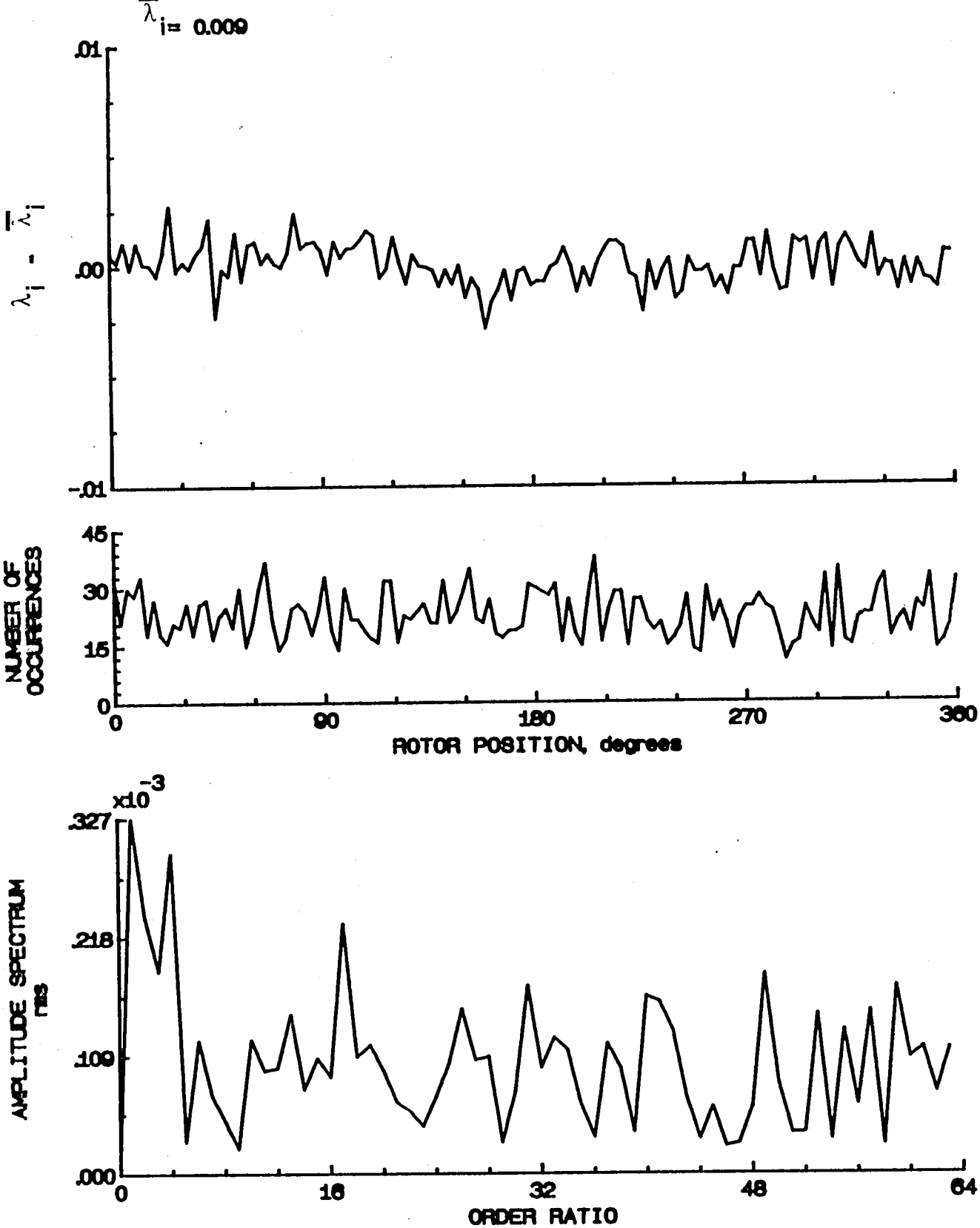


Figure 72.- Induced inflow velocity measured at 90 degrees and r/R of 1.10.



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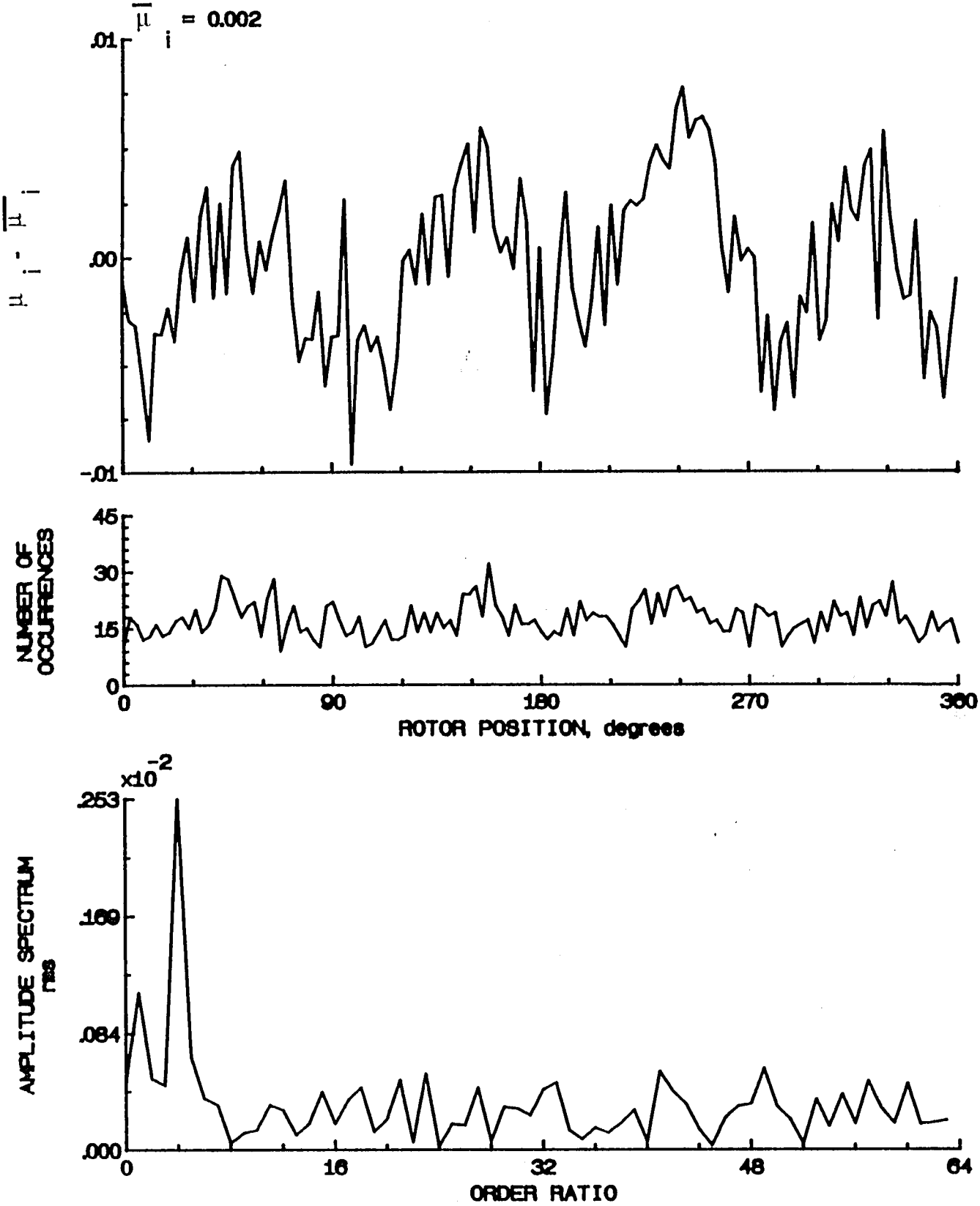
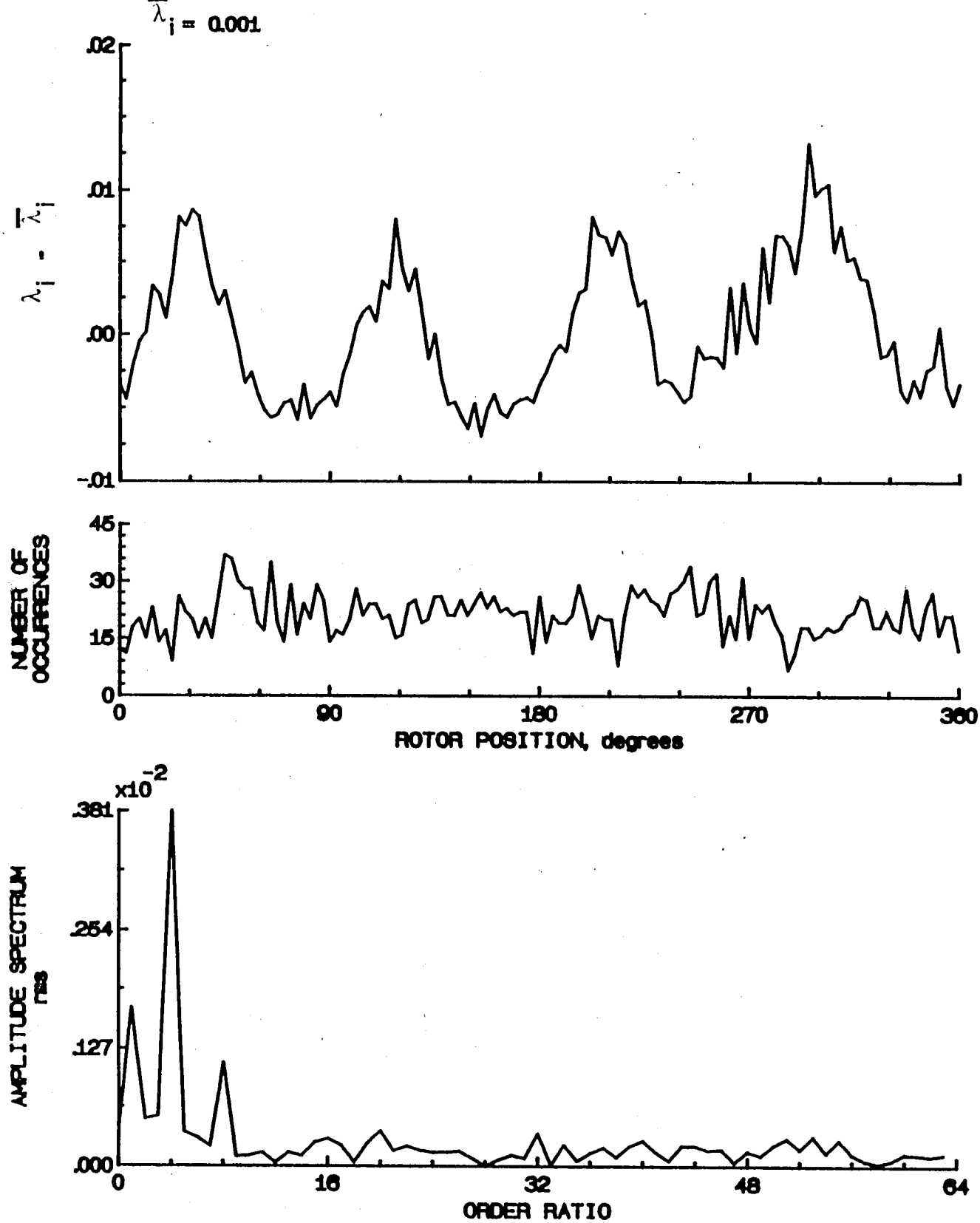


Figure 73.- Induced inflow velocity measured at 120 degrees and r/R of 0.20.



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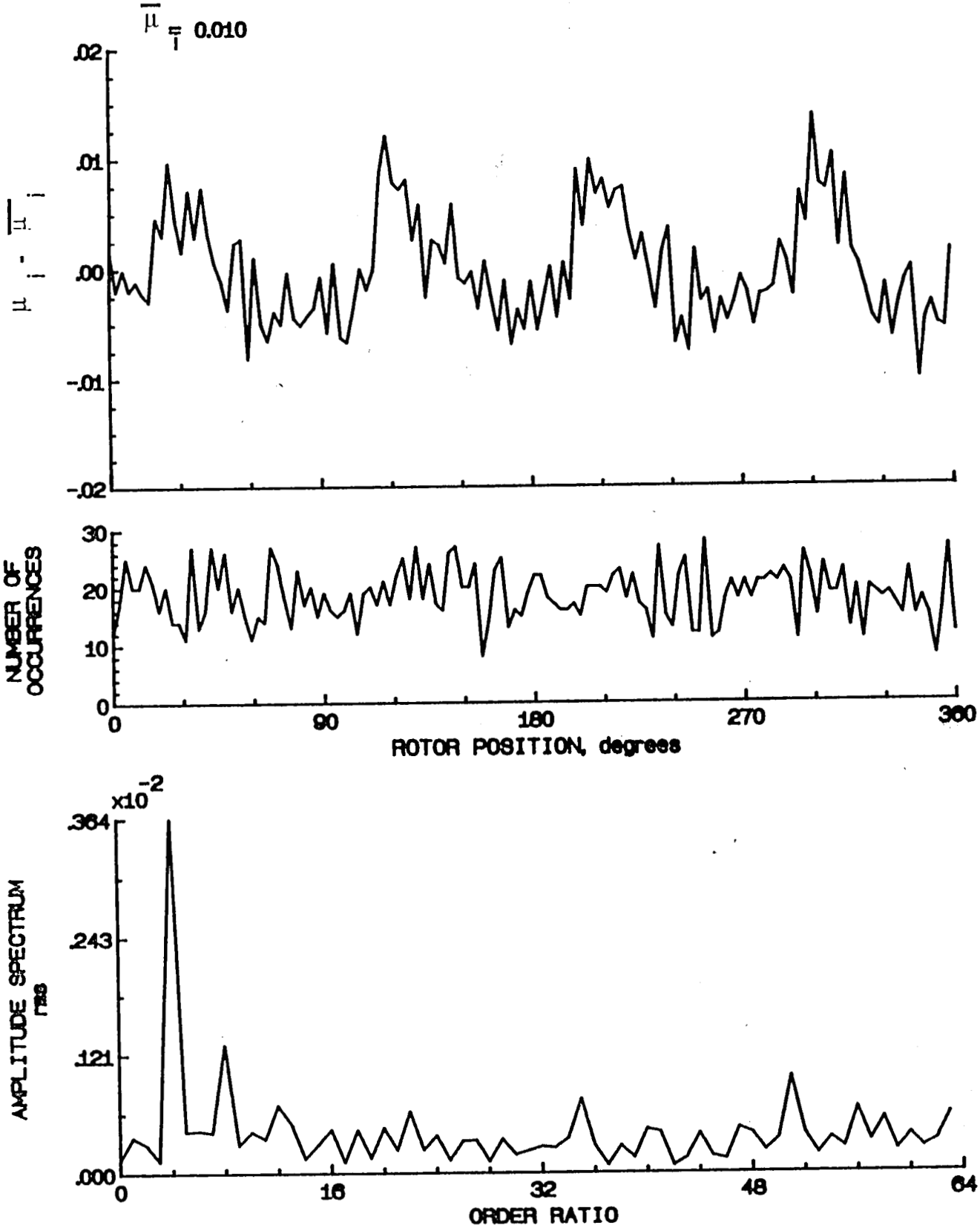
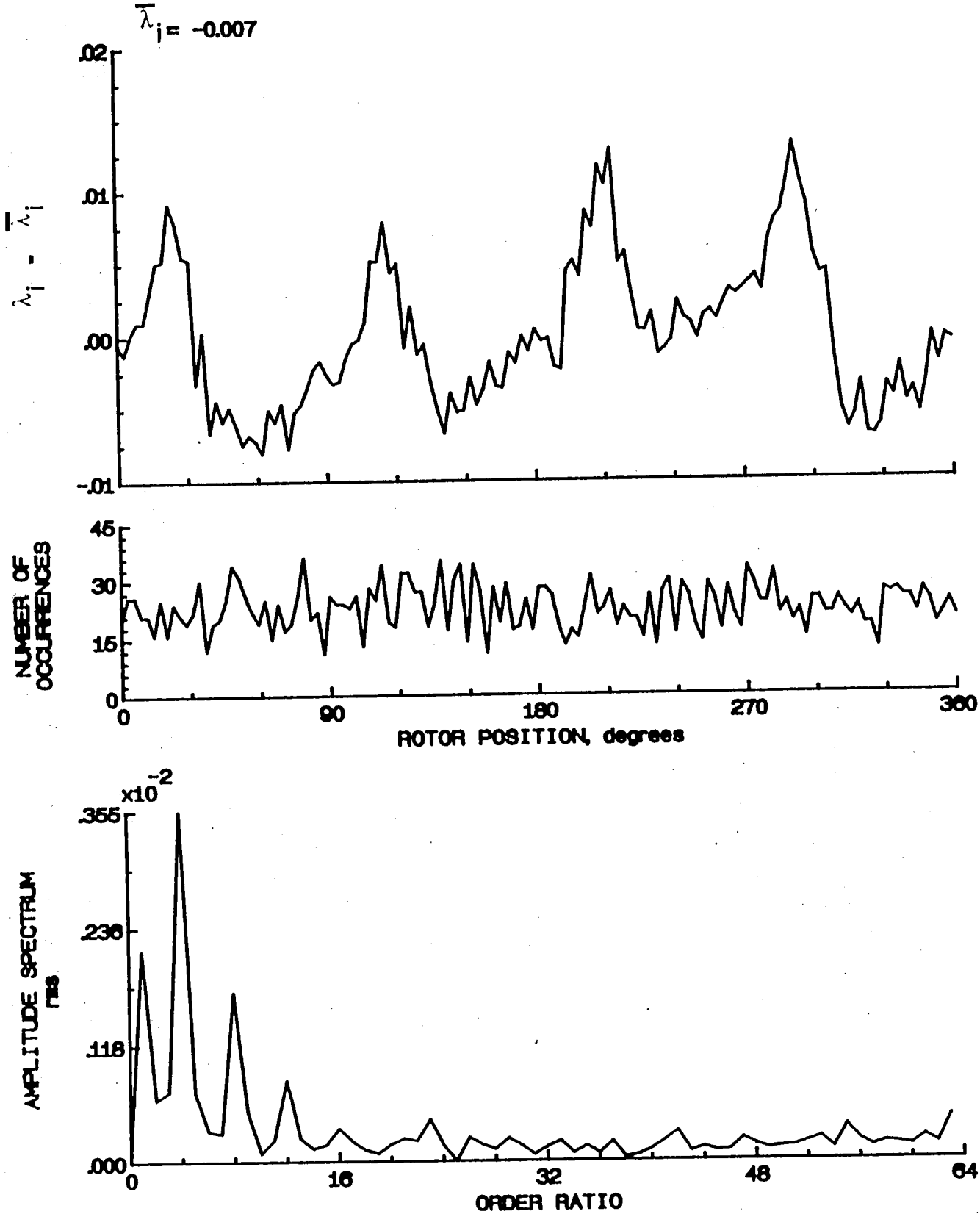


Figure 74.- Induced inflow velocity measured at 120 degrees and r/R of 0.40.



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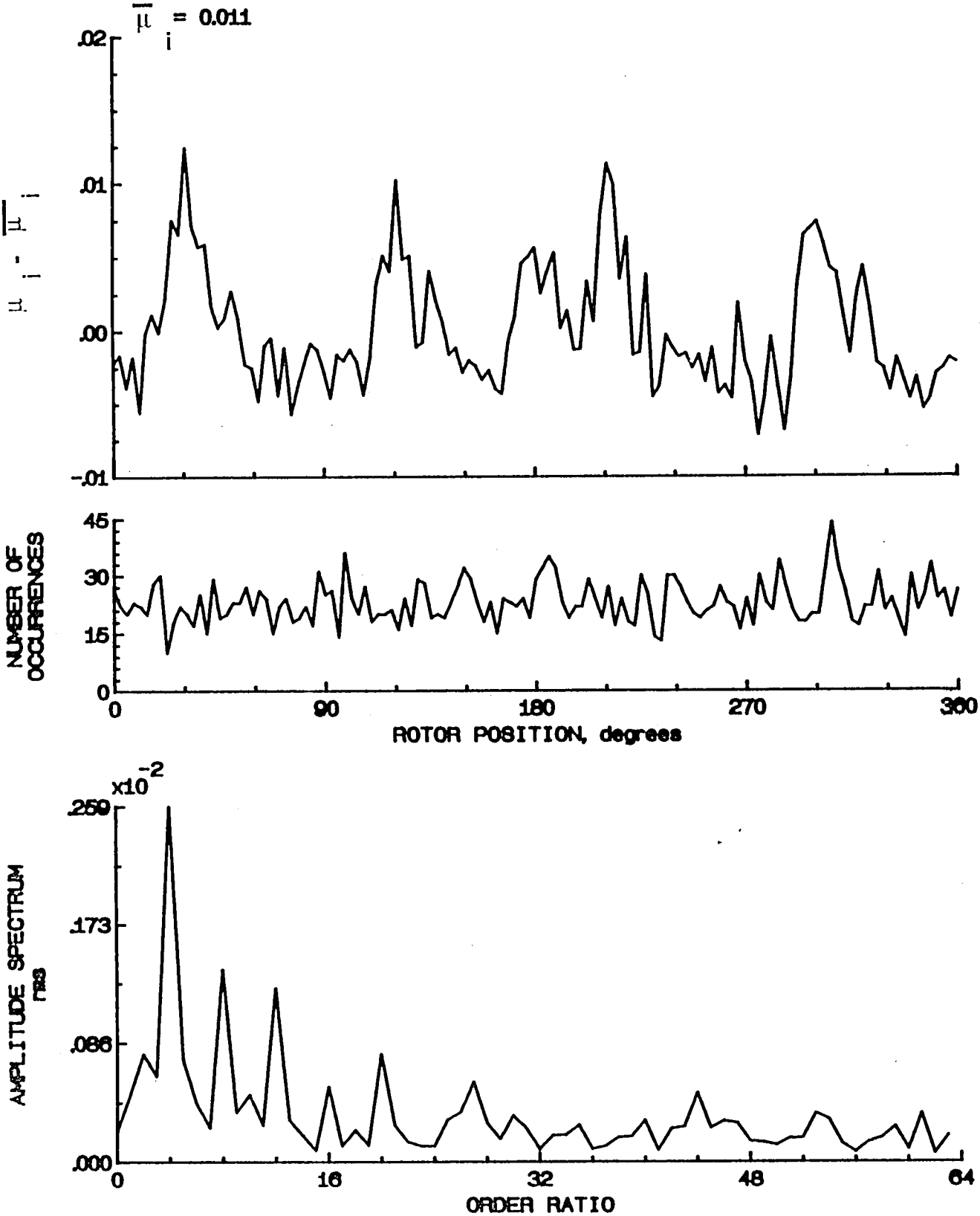
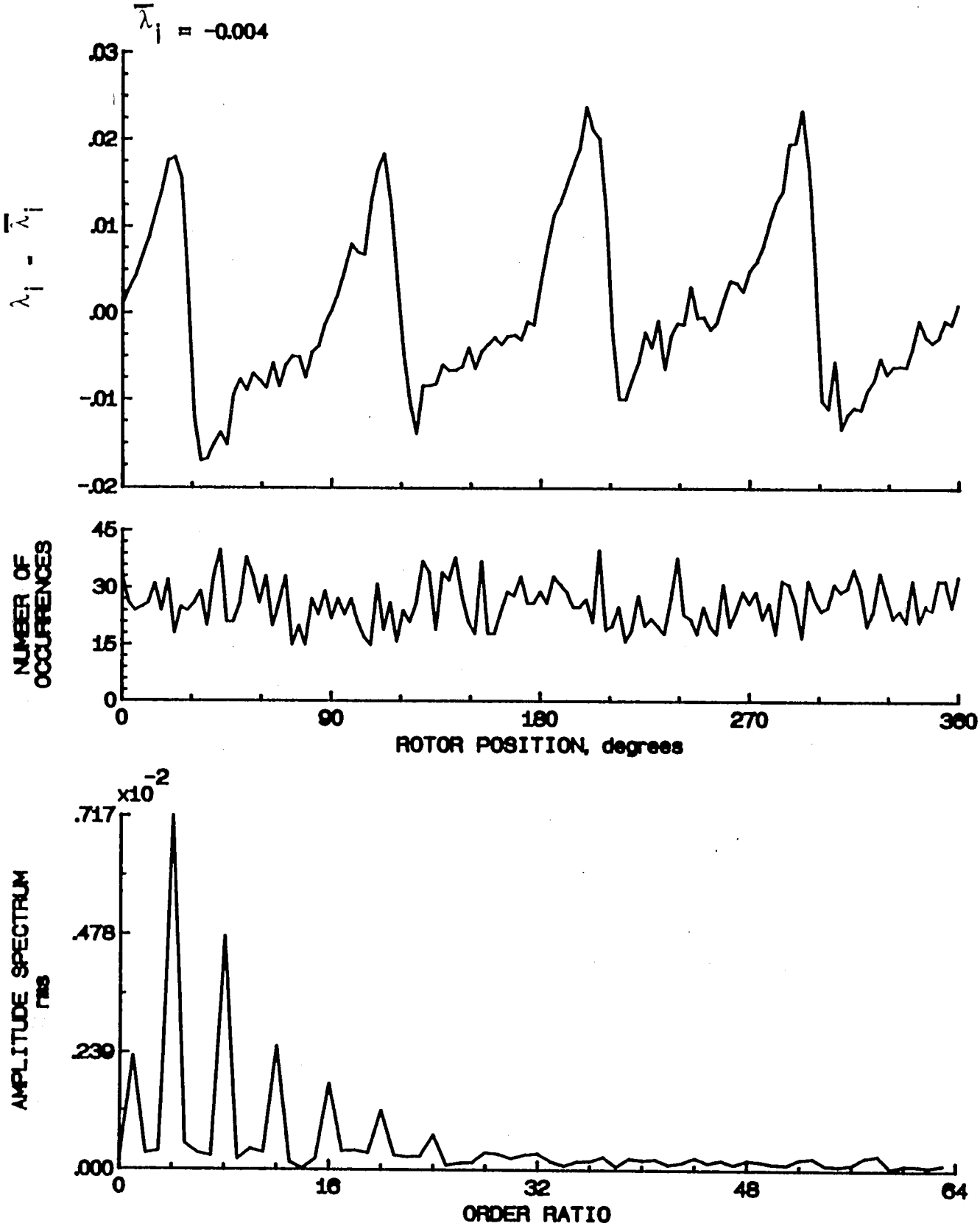


Figure 75.- Induced inflow velocity measured at 120 degrees and r/R of 0.50.



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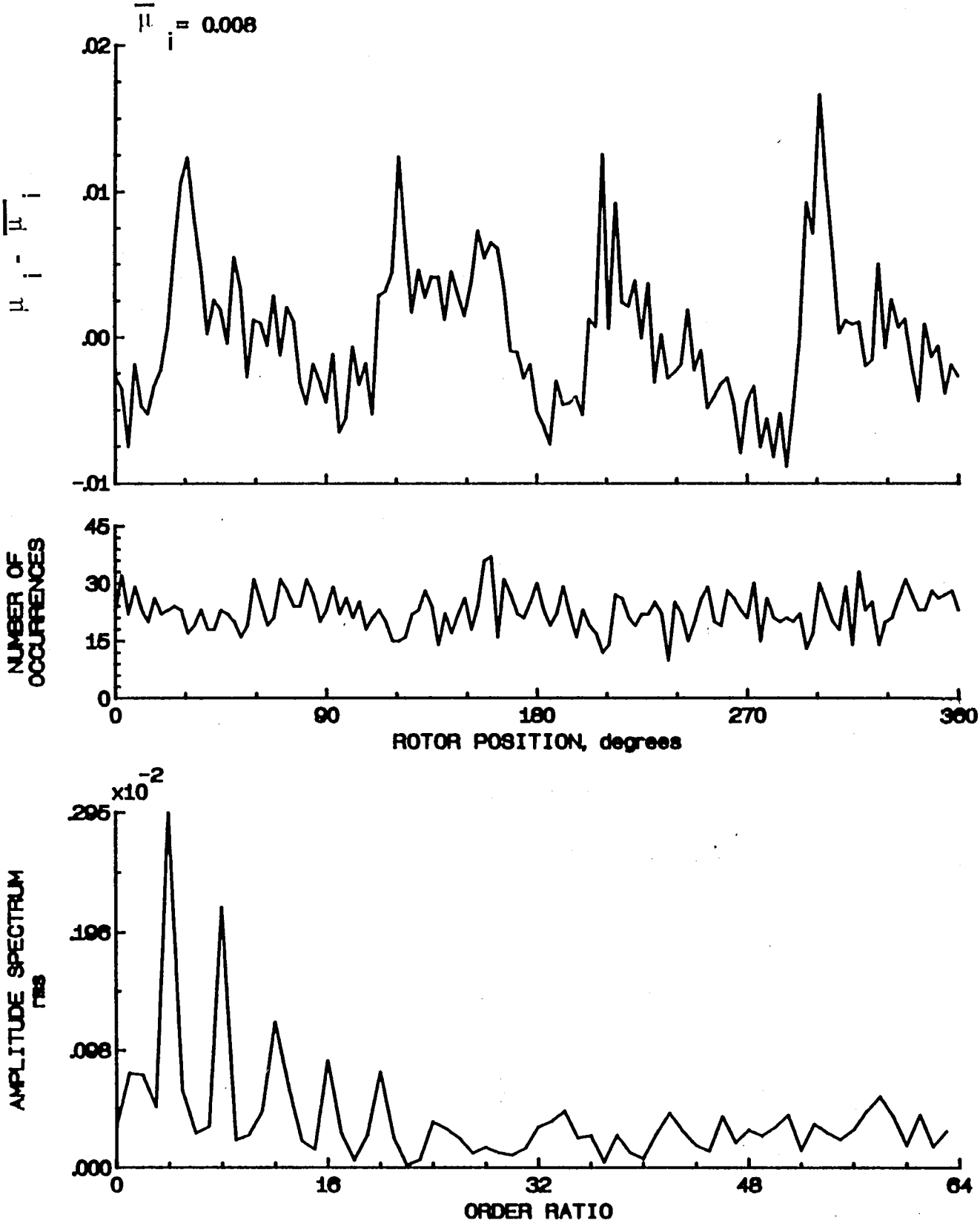


Figure 76.- Induced inflow velocity measured at 120 degrees and r/R of 0.60.

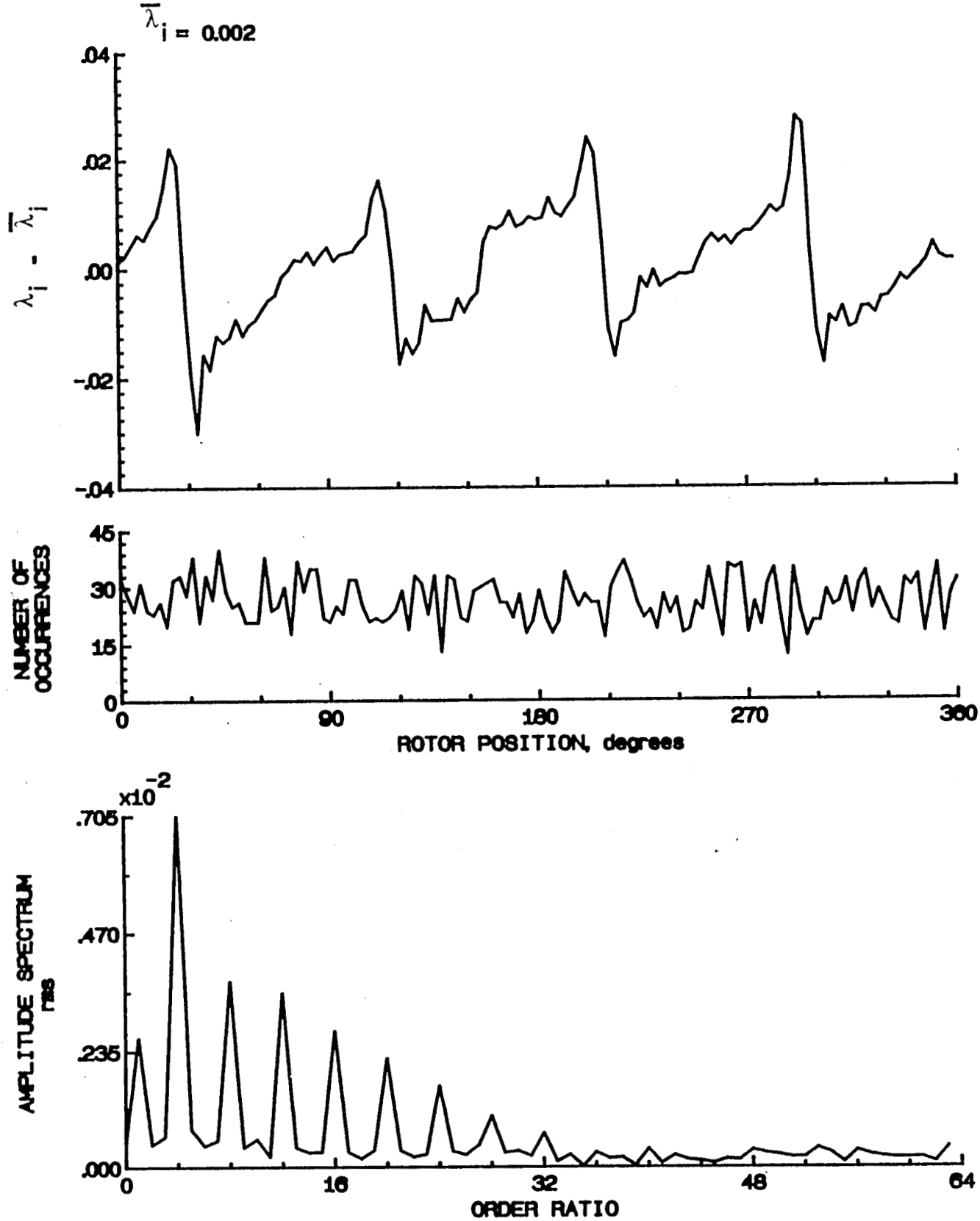


Figure 76.- Concluded.

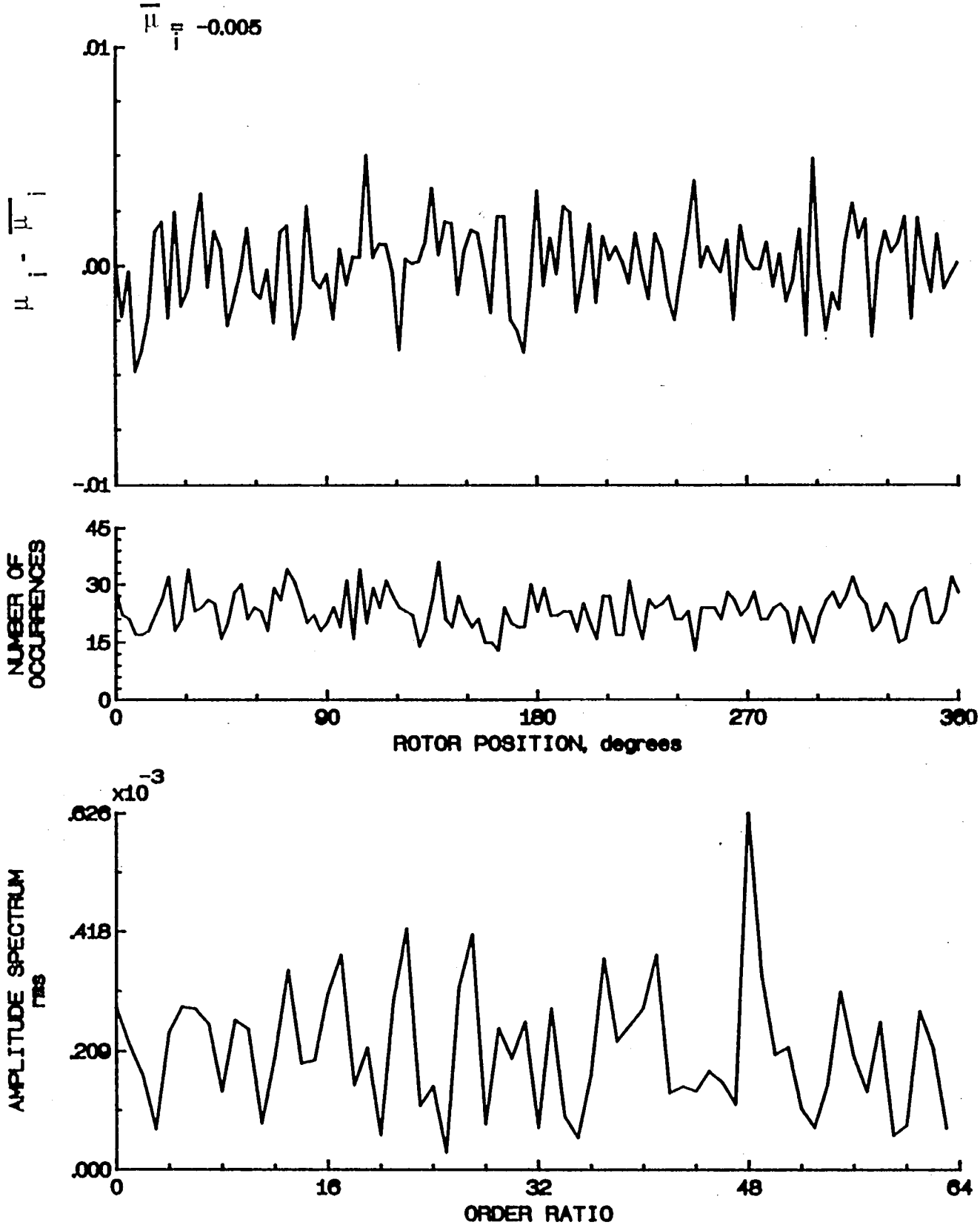
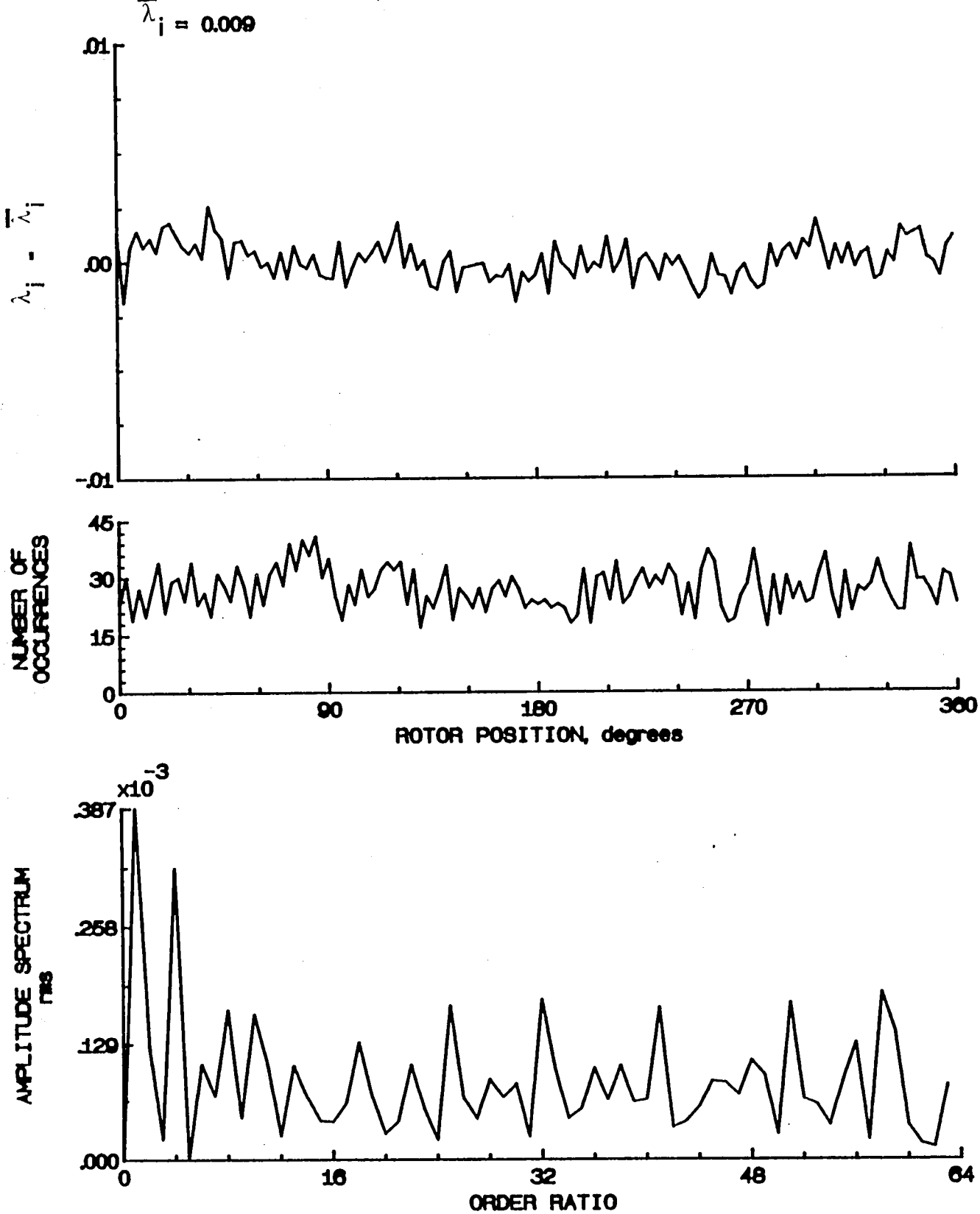


Figure 77.- Induced inflow velocity measured at 120 degrees and r/R of 0.70.



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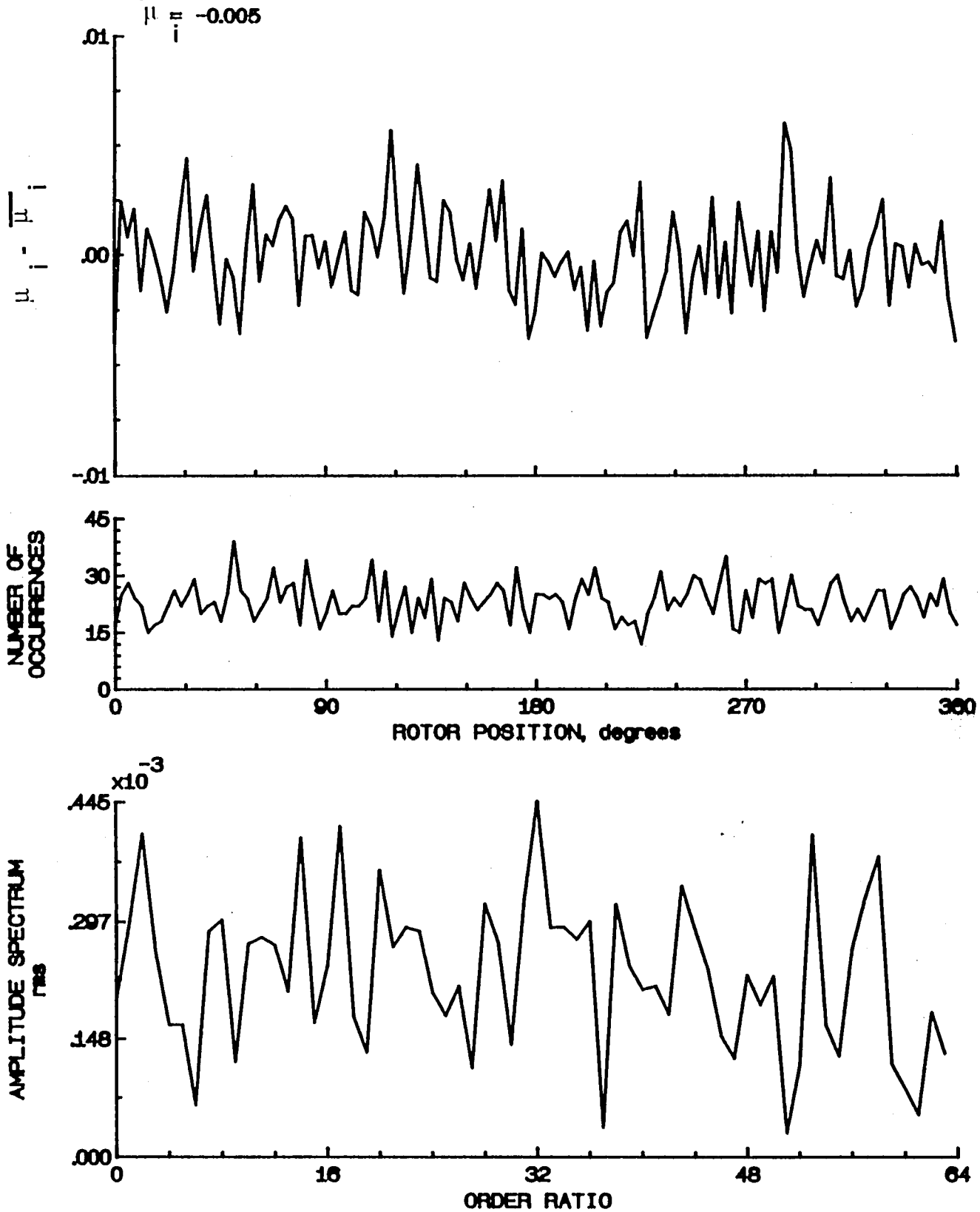
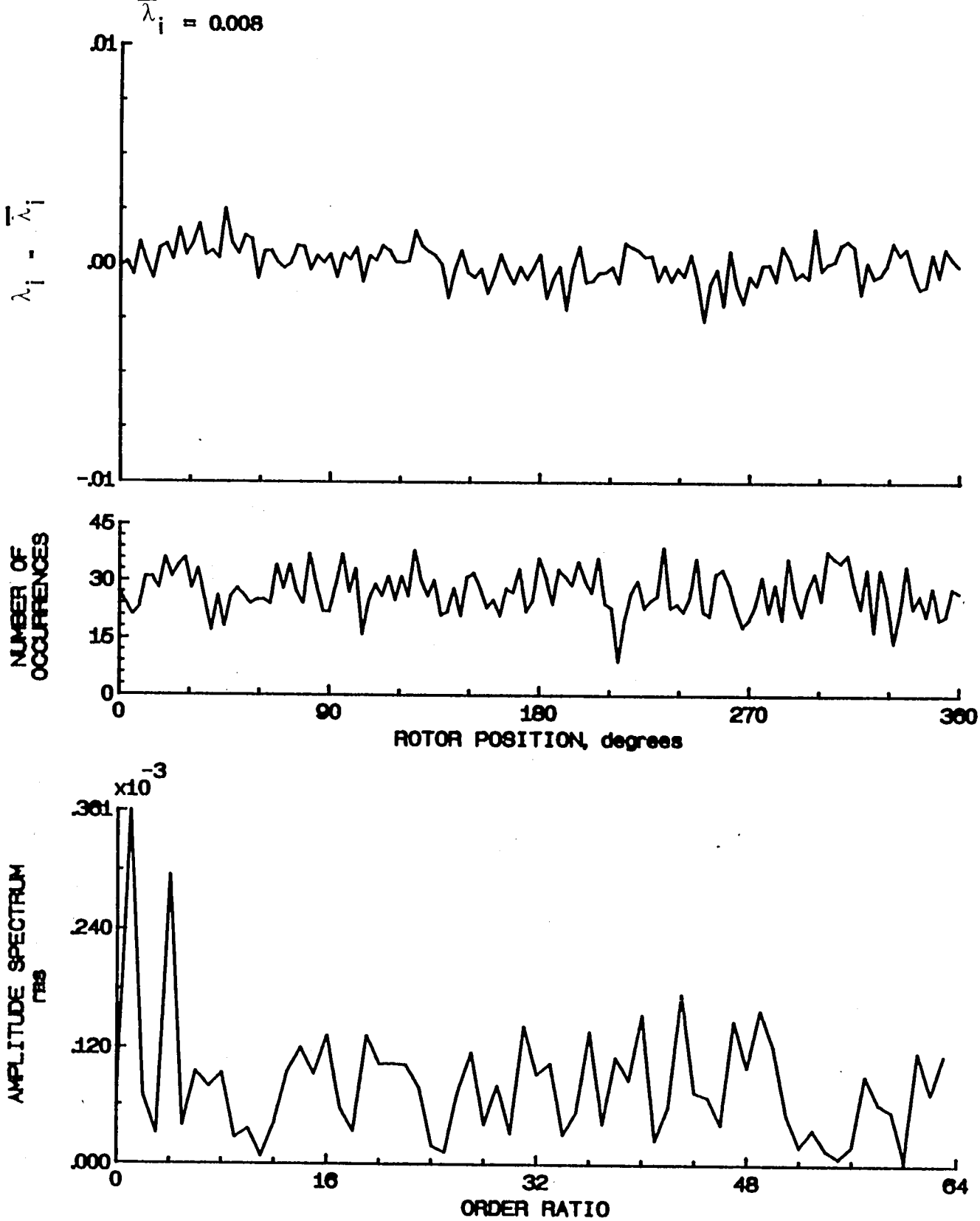


Figure 78.- Induced inflow velocity measured at 120 degrees and r/R of 0.74.



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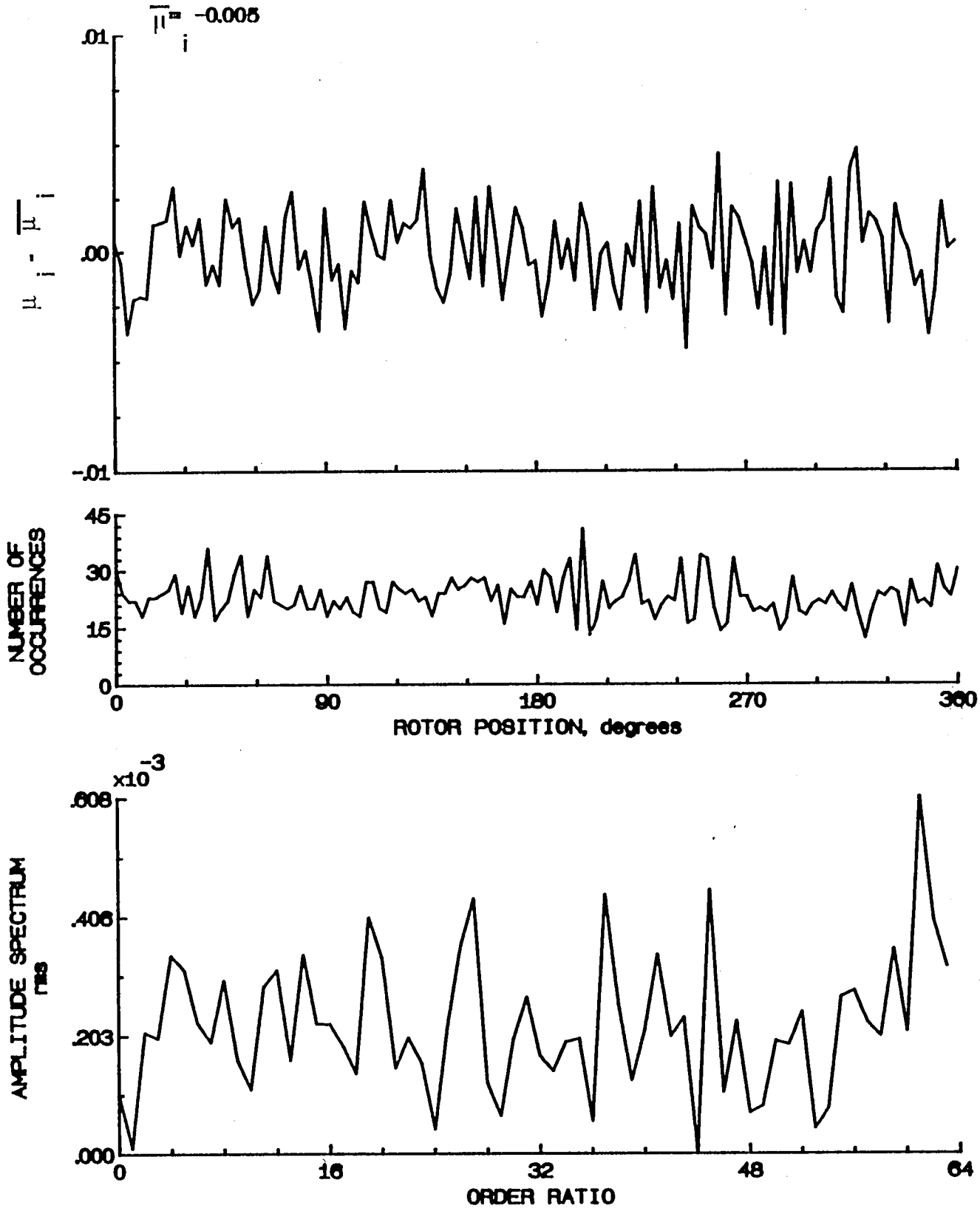
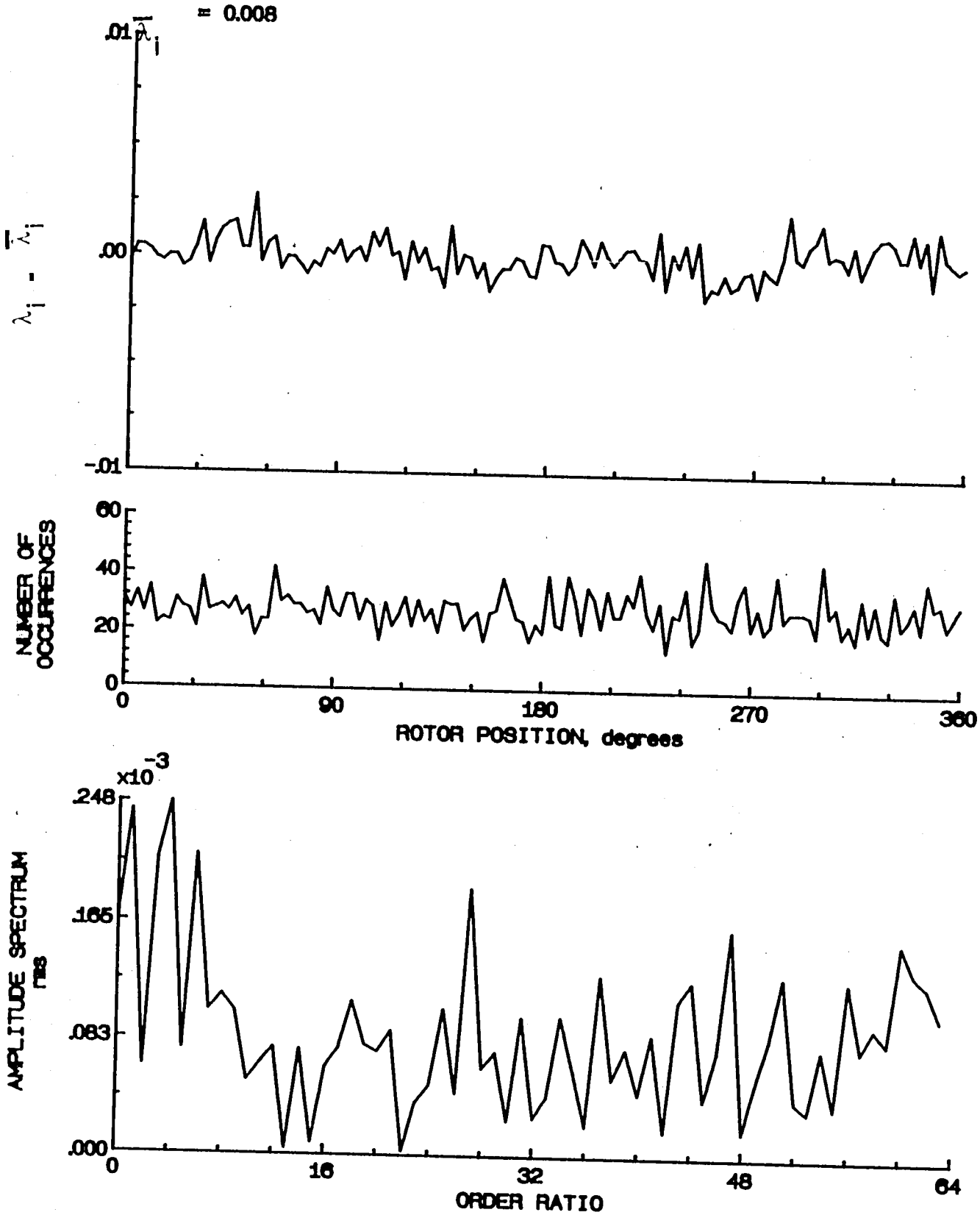


Figure 79.- Induced inflow velocity measured at 120 degrees and r/R of 0.78.



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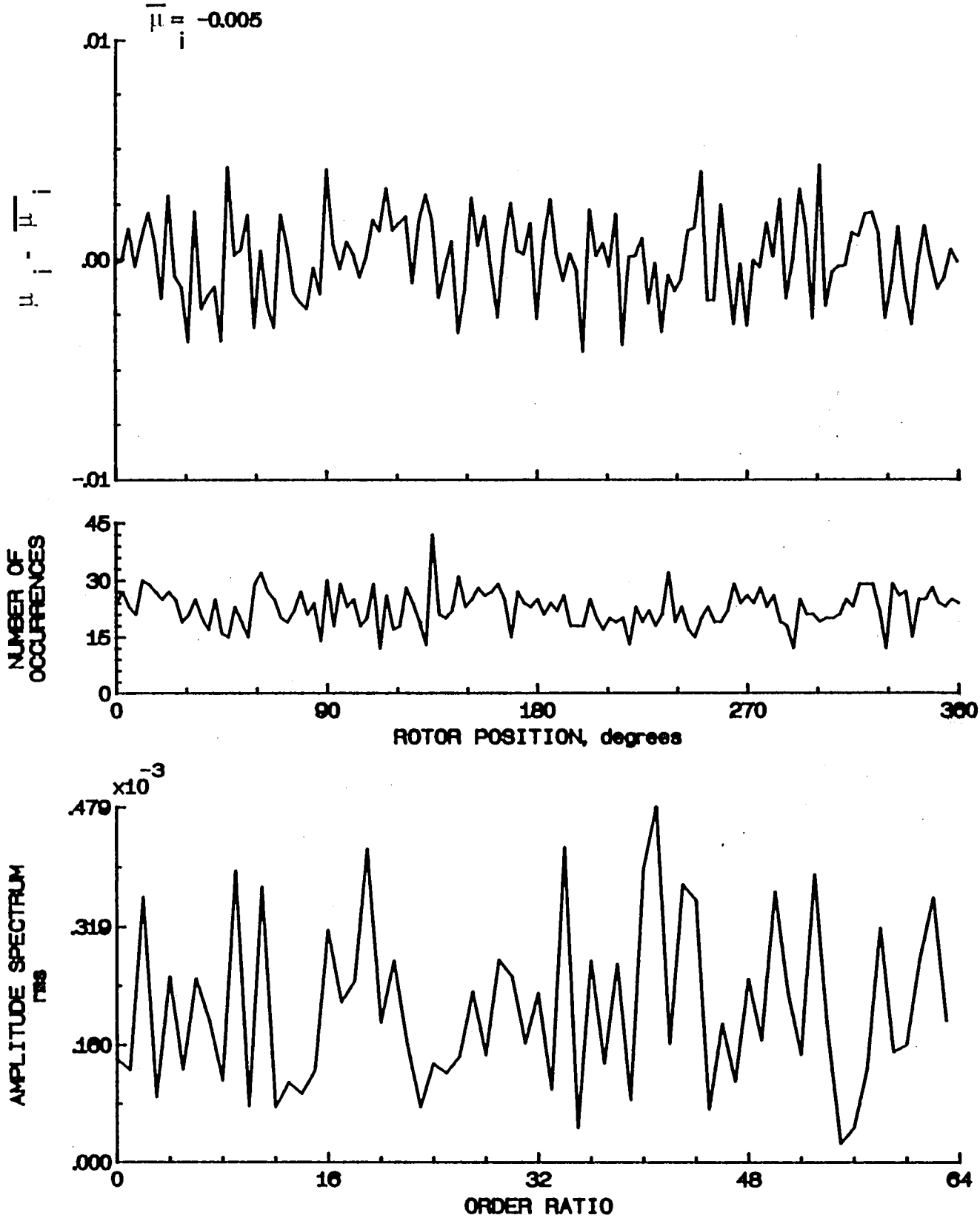
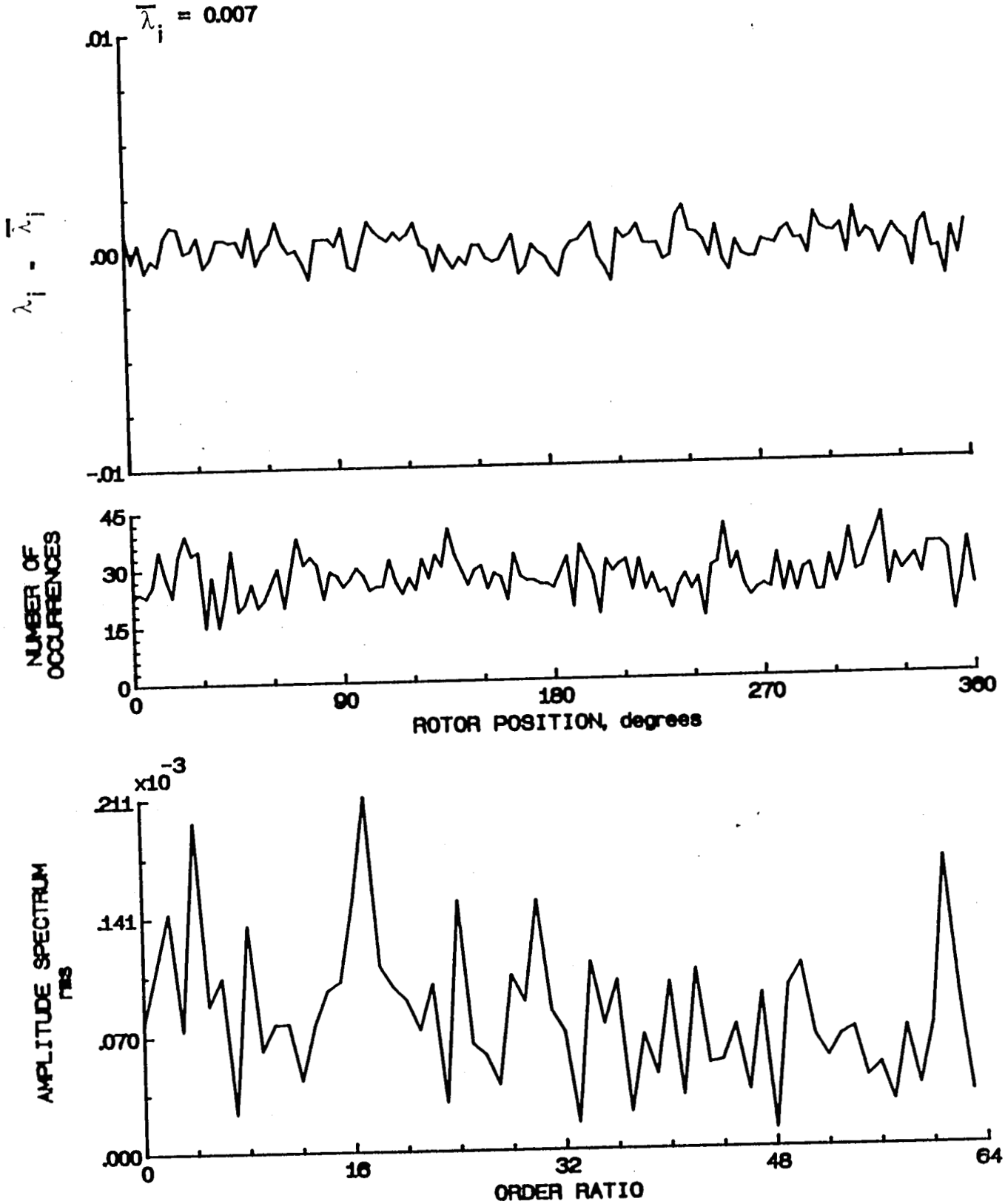


Figure 80.- Induced inflow velocity measured at 120 degrees and r/R of 0.82.



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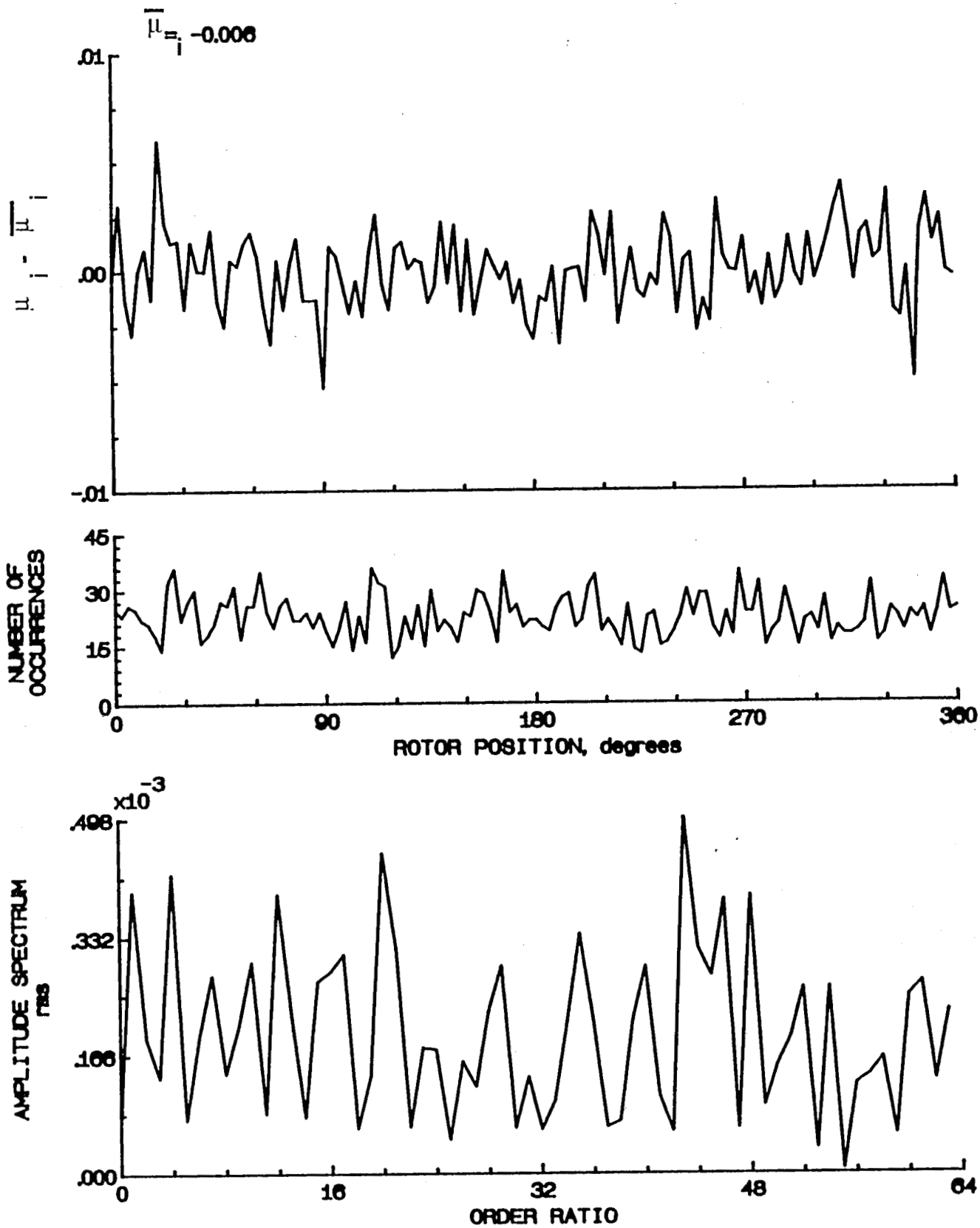
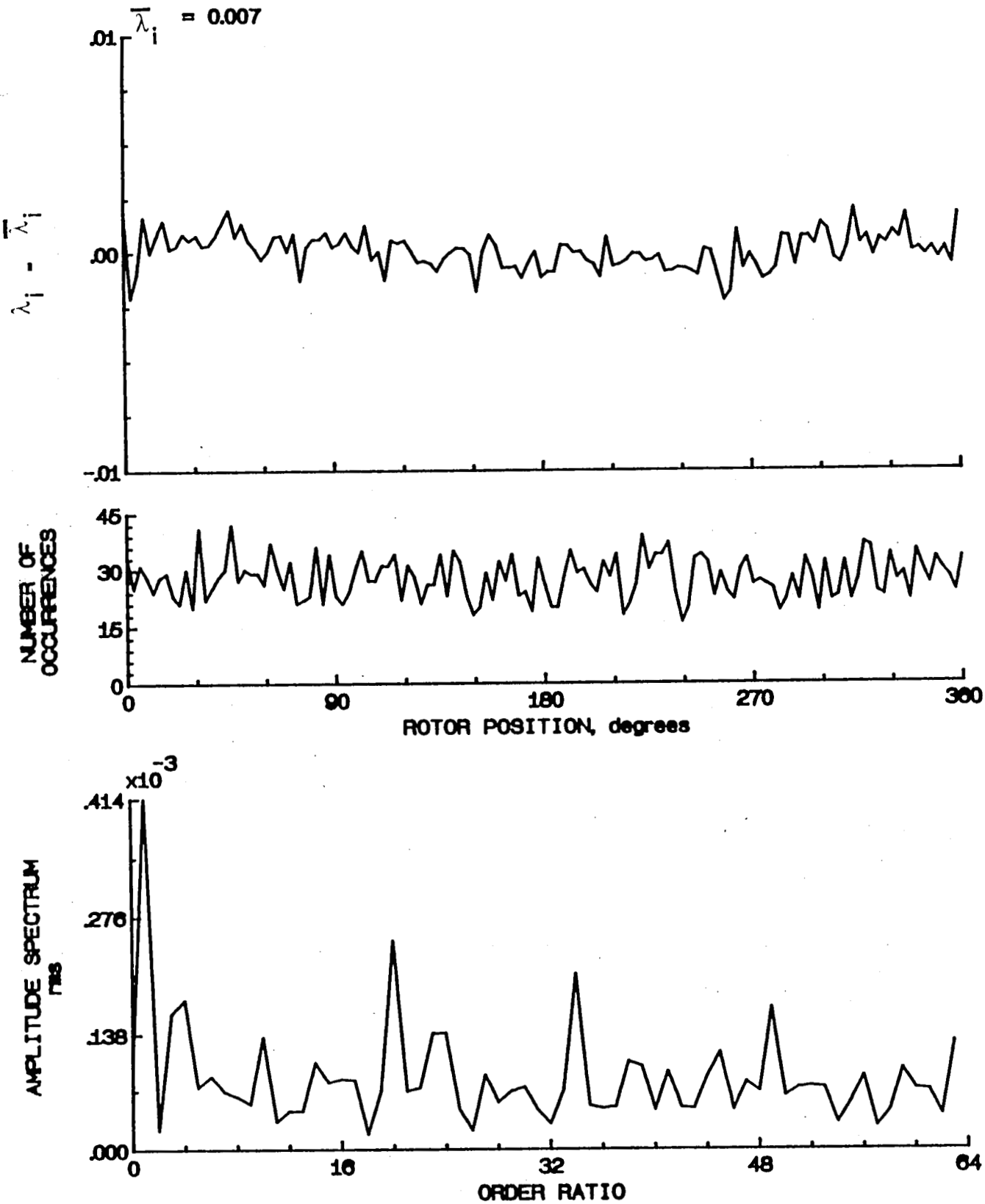


Figure 81.- Induced inflow velocity measured at 120 degrees and r/R of 0.86.



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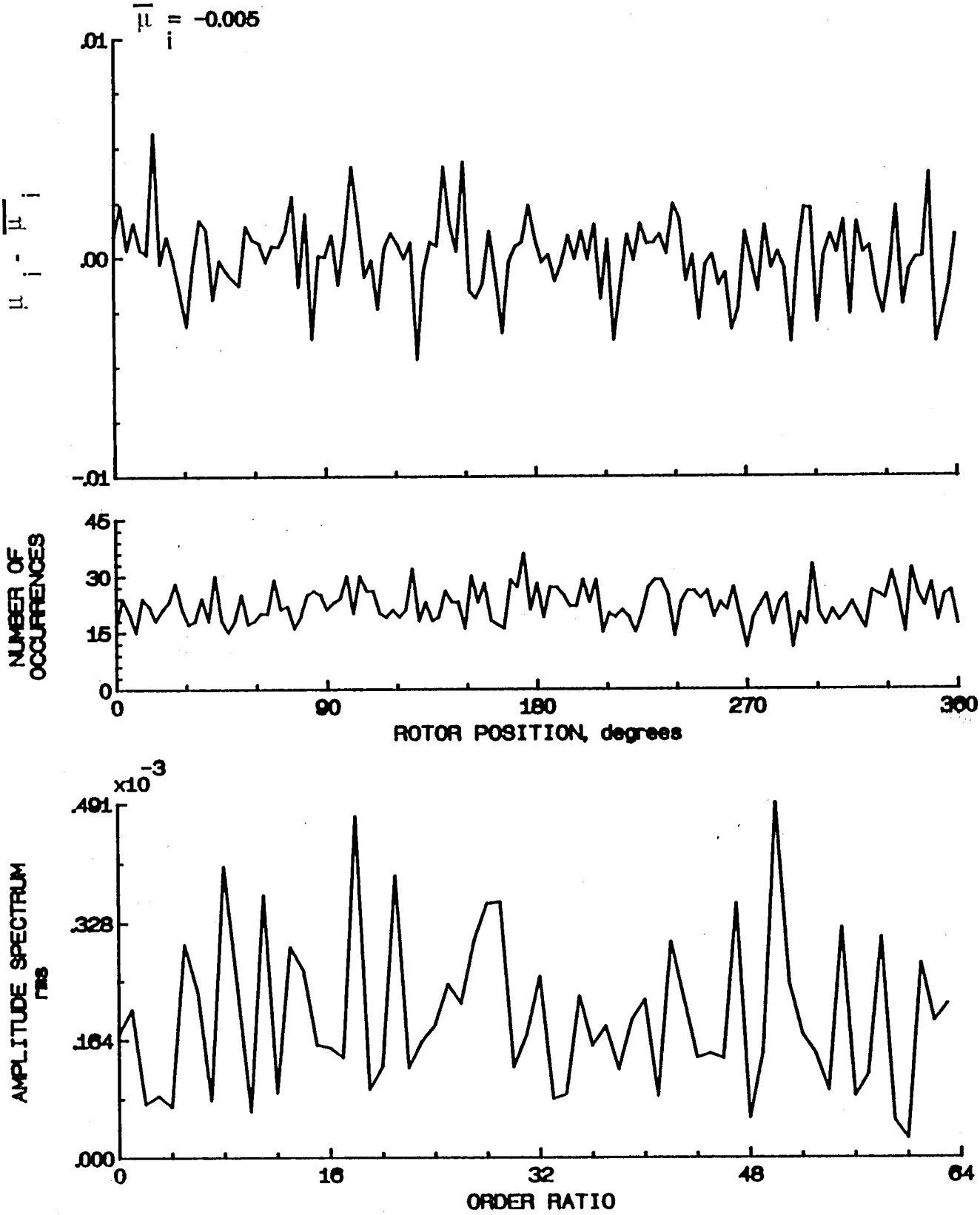
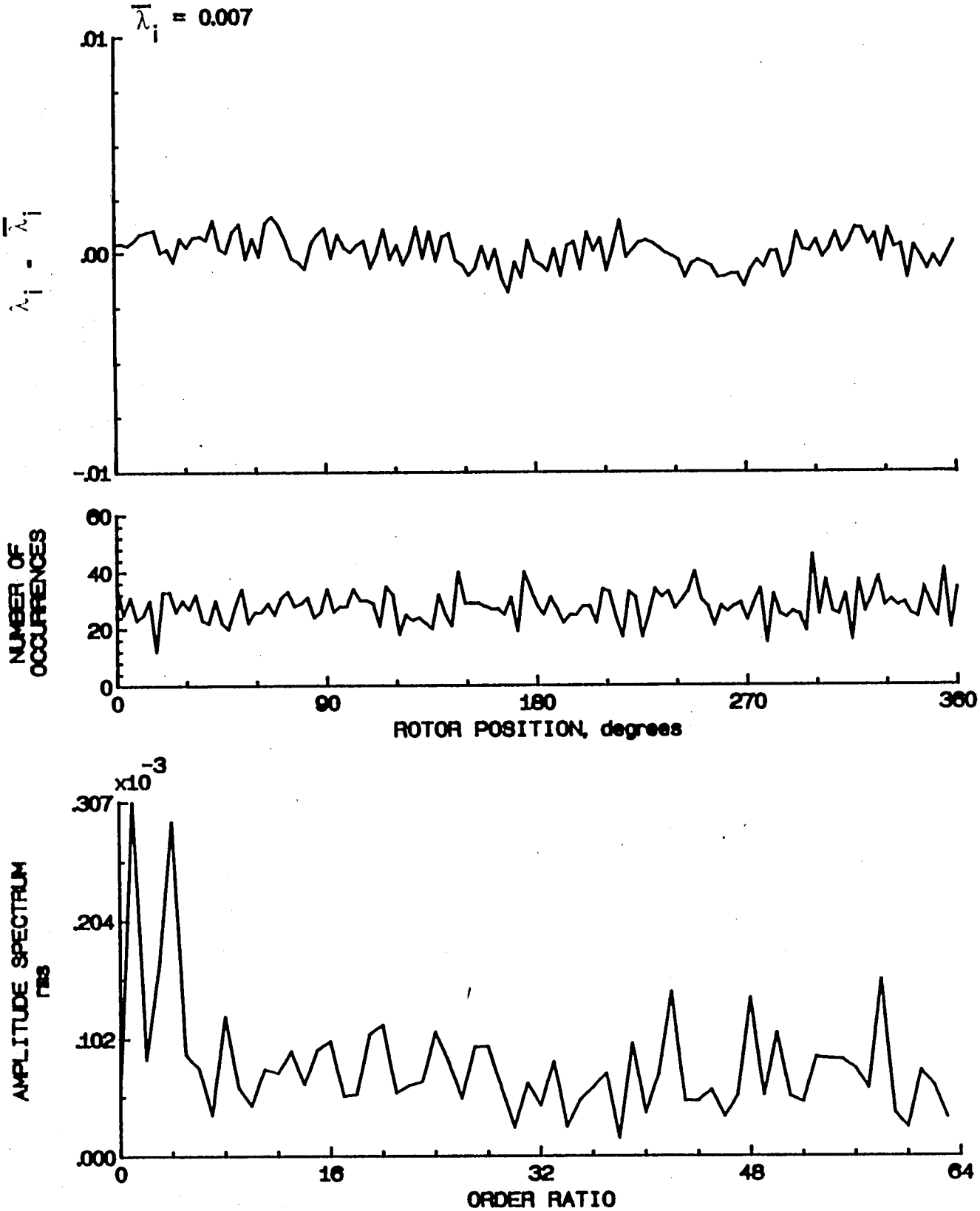


Figure 82.- Induced inflow velocity measured at 120 degrees and r/R of 0.90.



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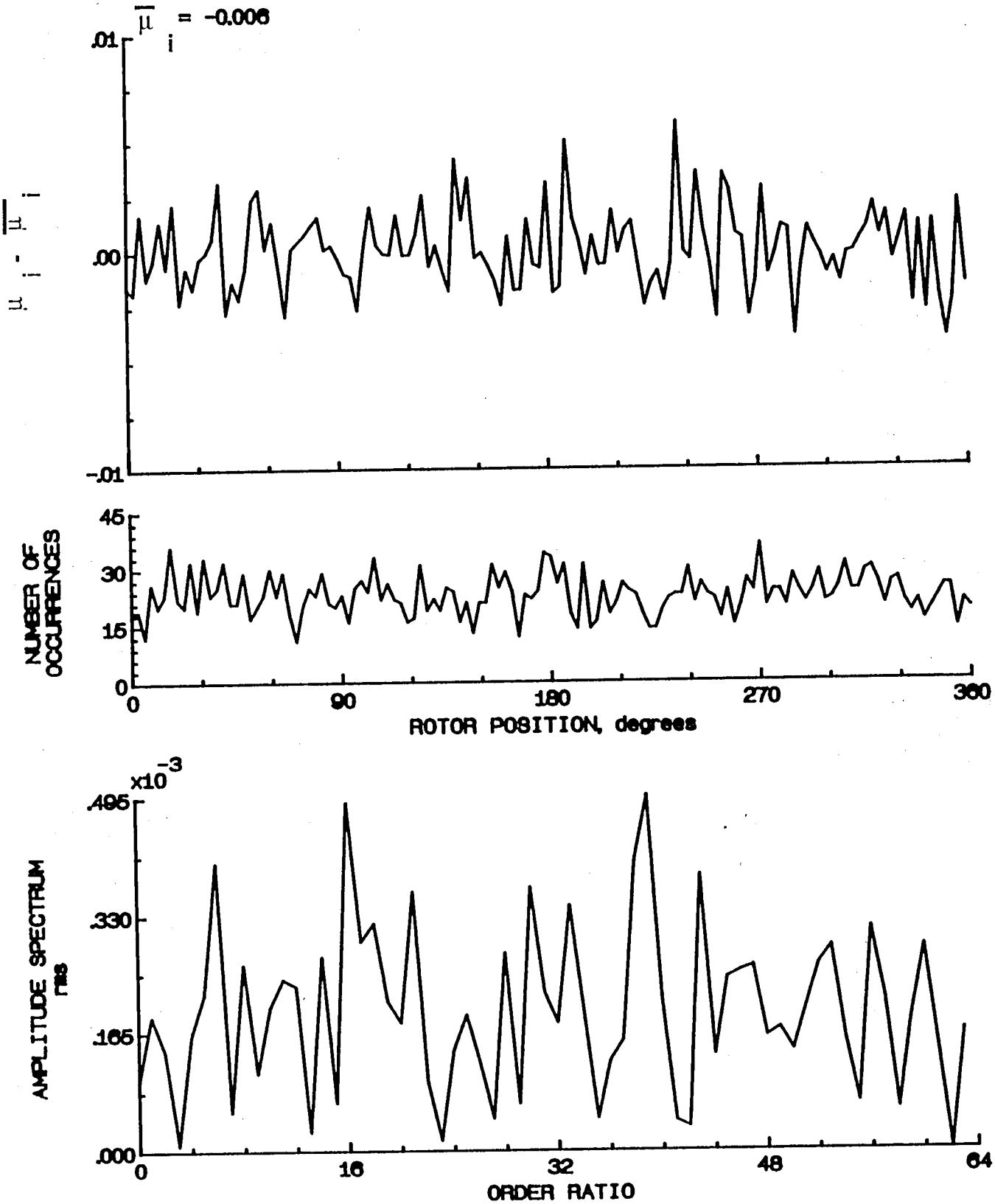
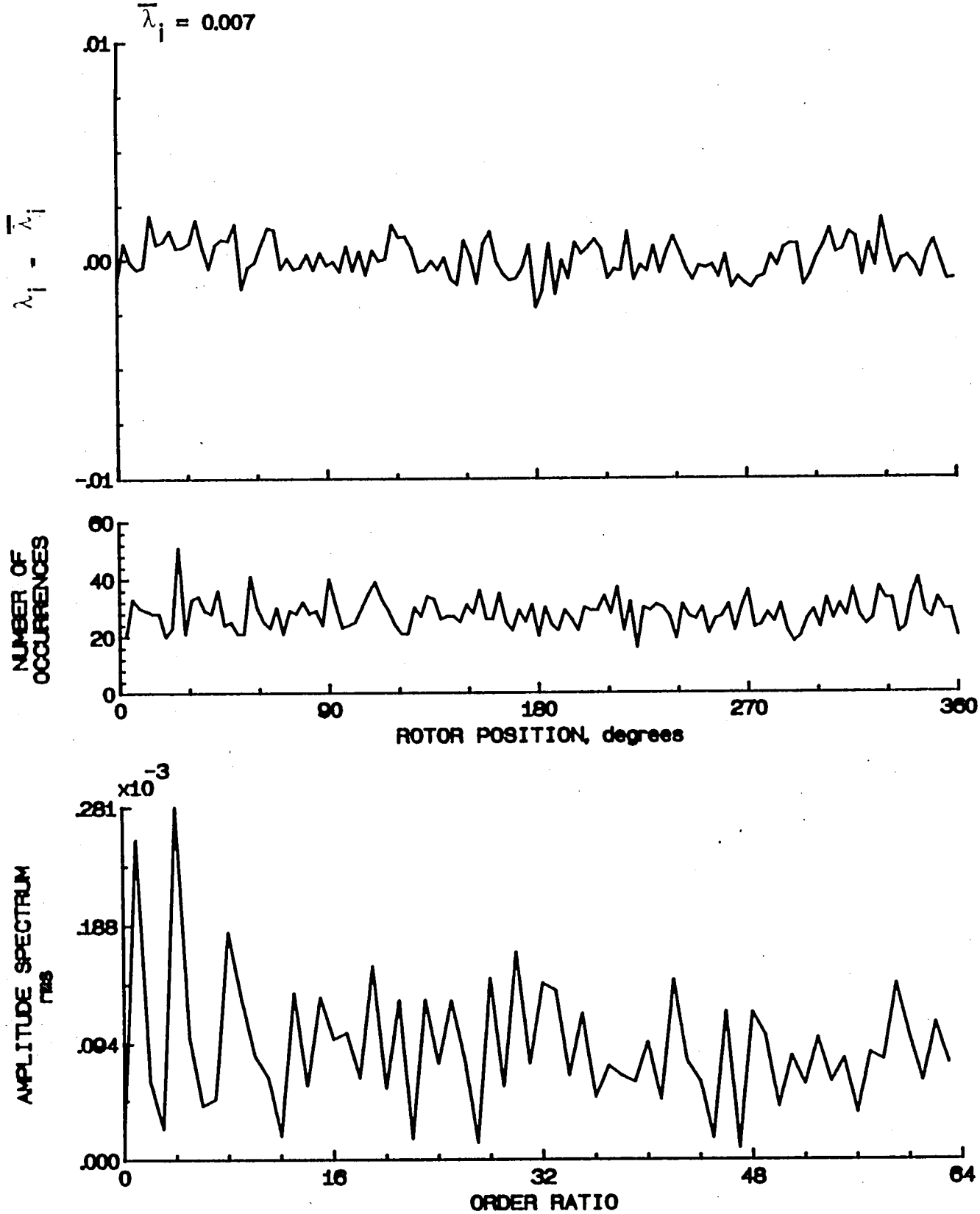


Figure 83.- Induced inflow velocity measured at 120 degrees and r/R of 0.94.



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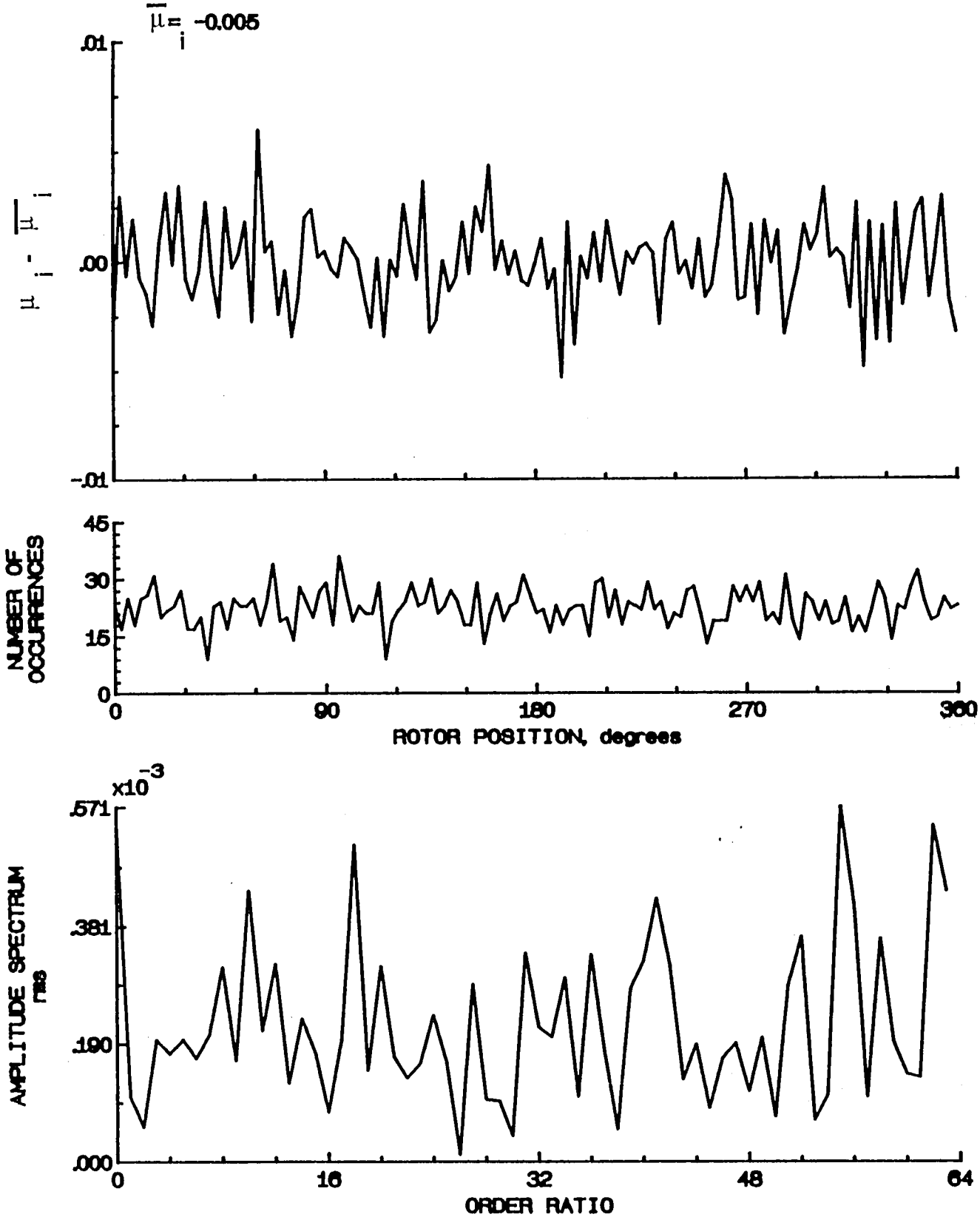
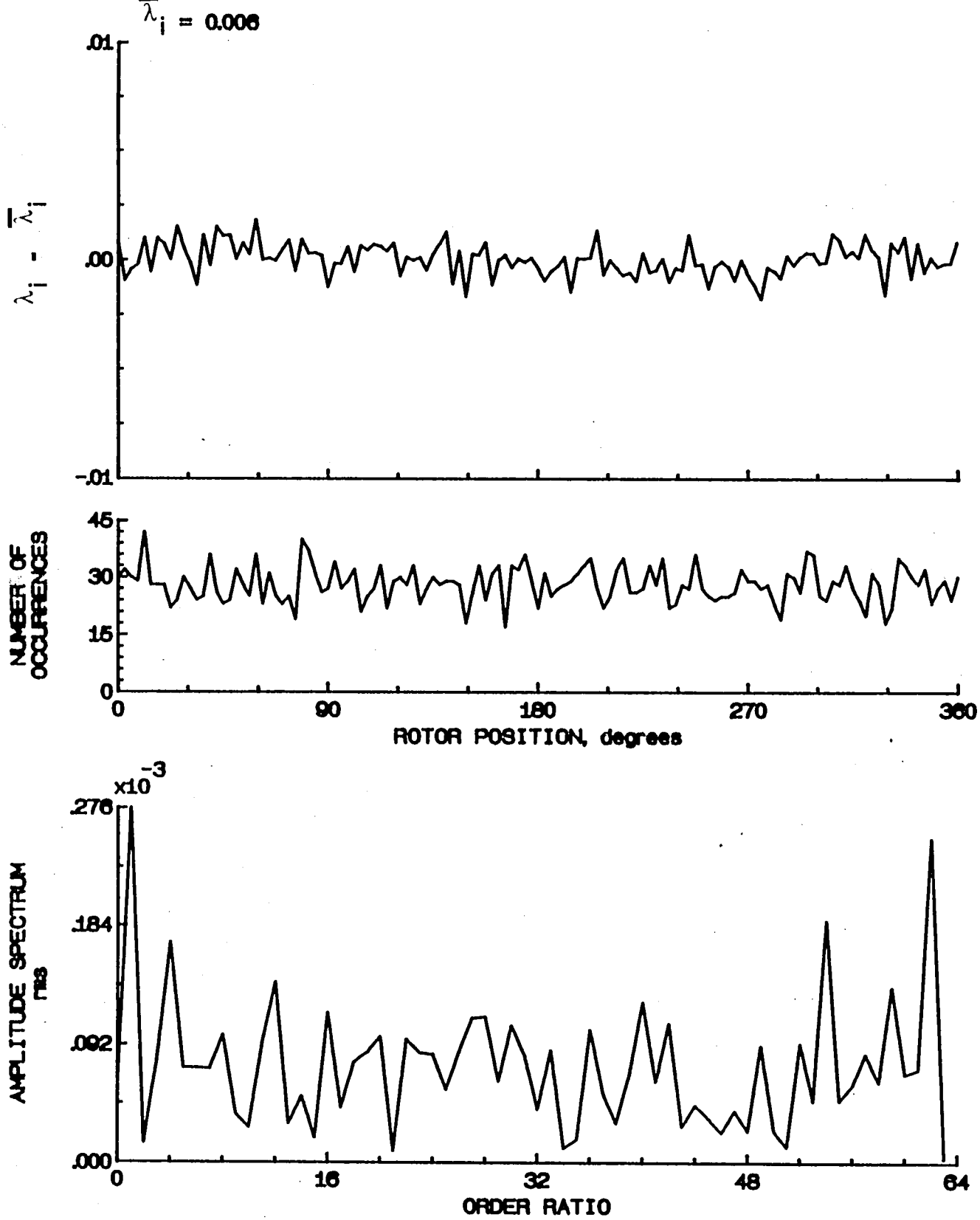


Figure 84.- Induced inflow velocity measured at 120 degrees and r/R of 0.98.



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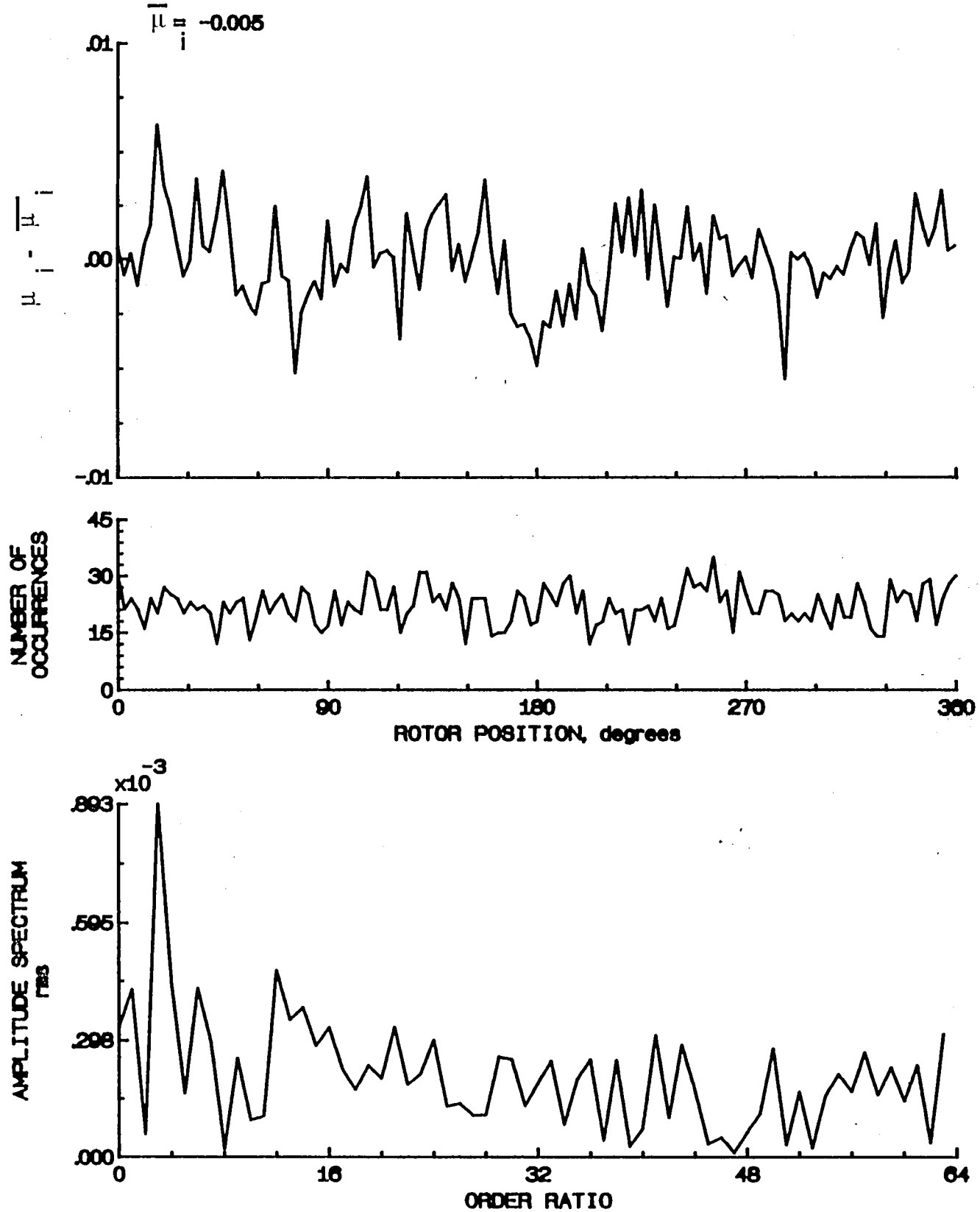
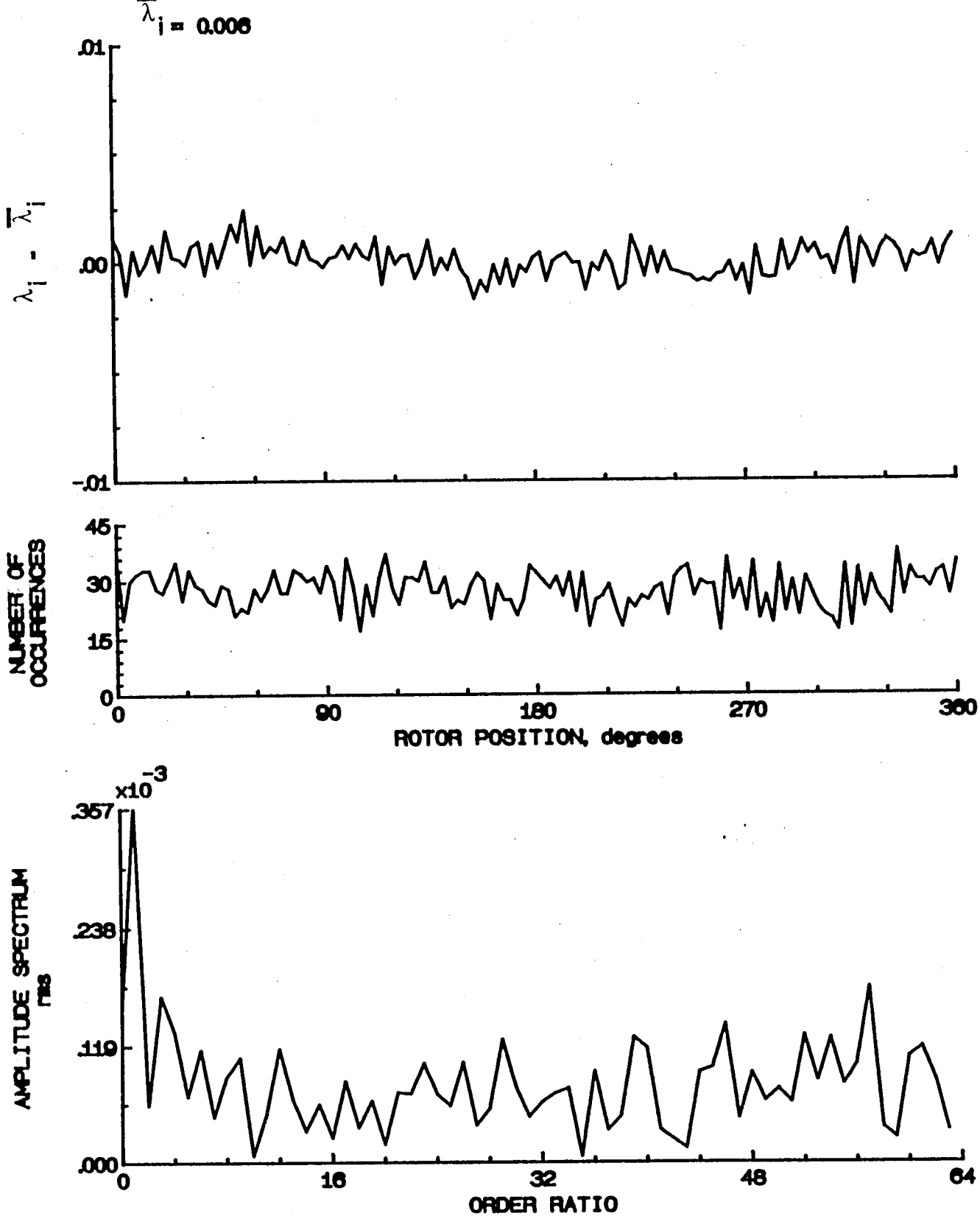


Figure 85.- Induced inflow velocity measured at 120 degrees and r/R of 1.02.



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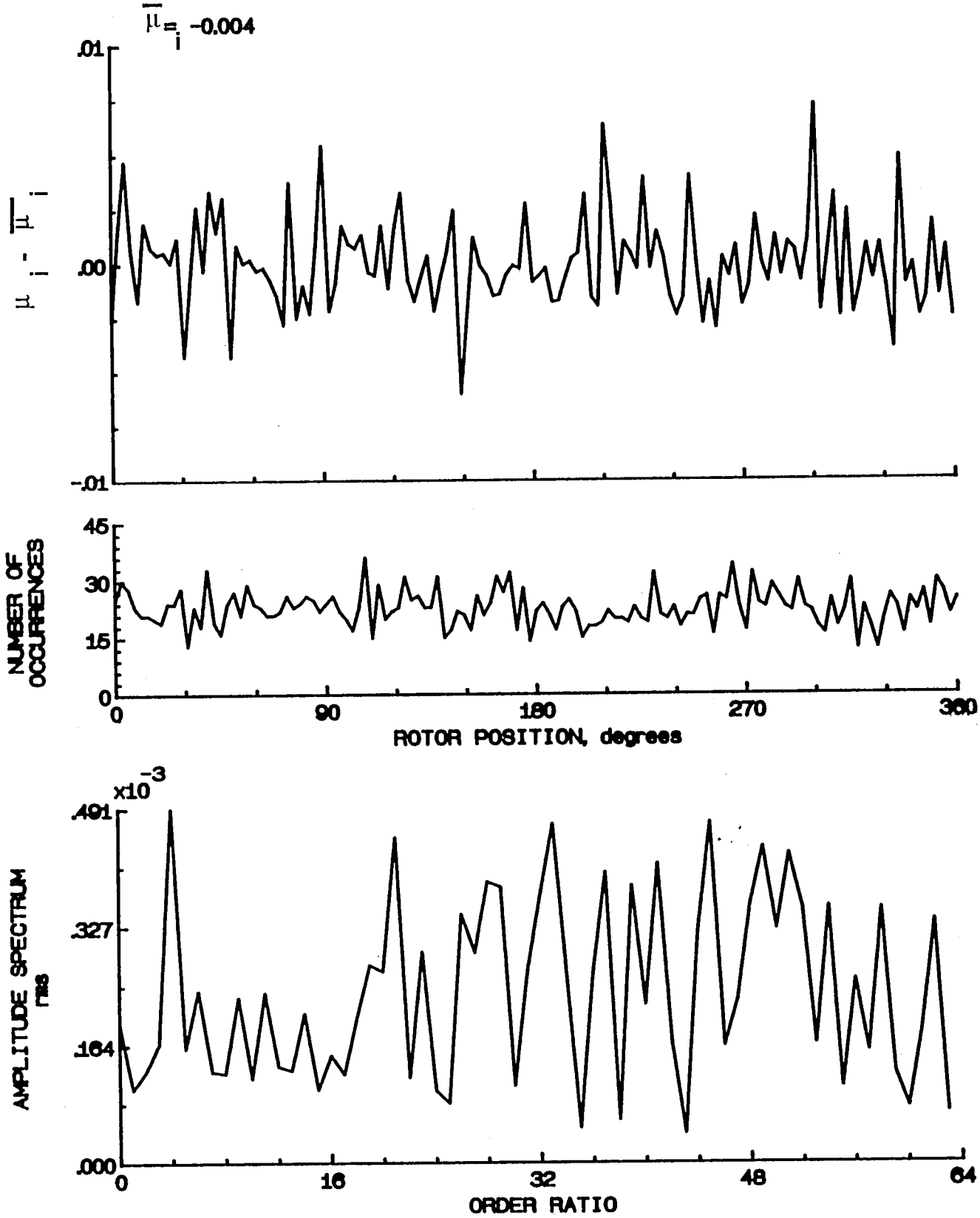
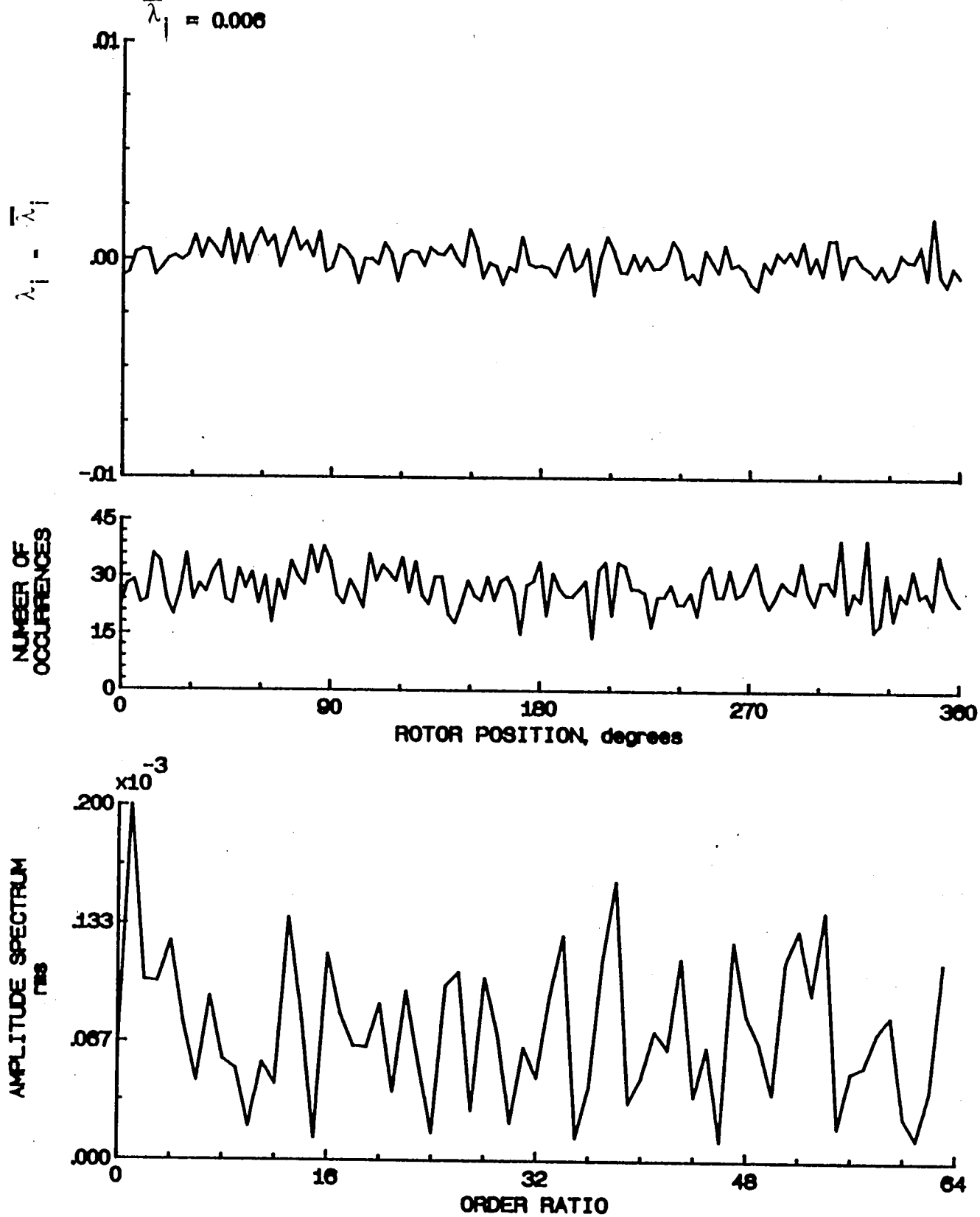


Figure 86.- Induced inflow velocity measured at 120 degrees and r/R of 1.04.



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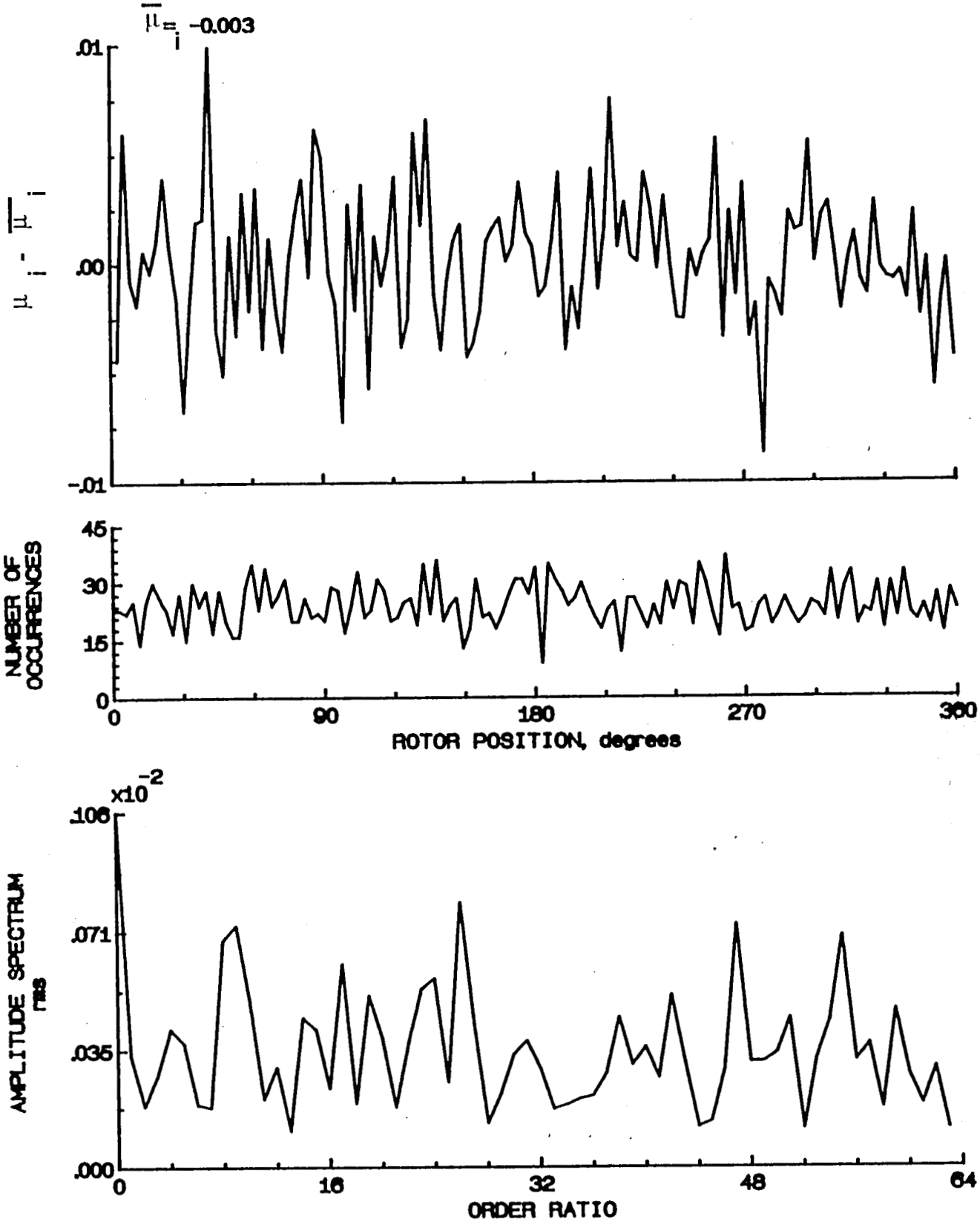
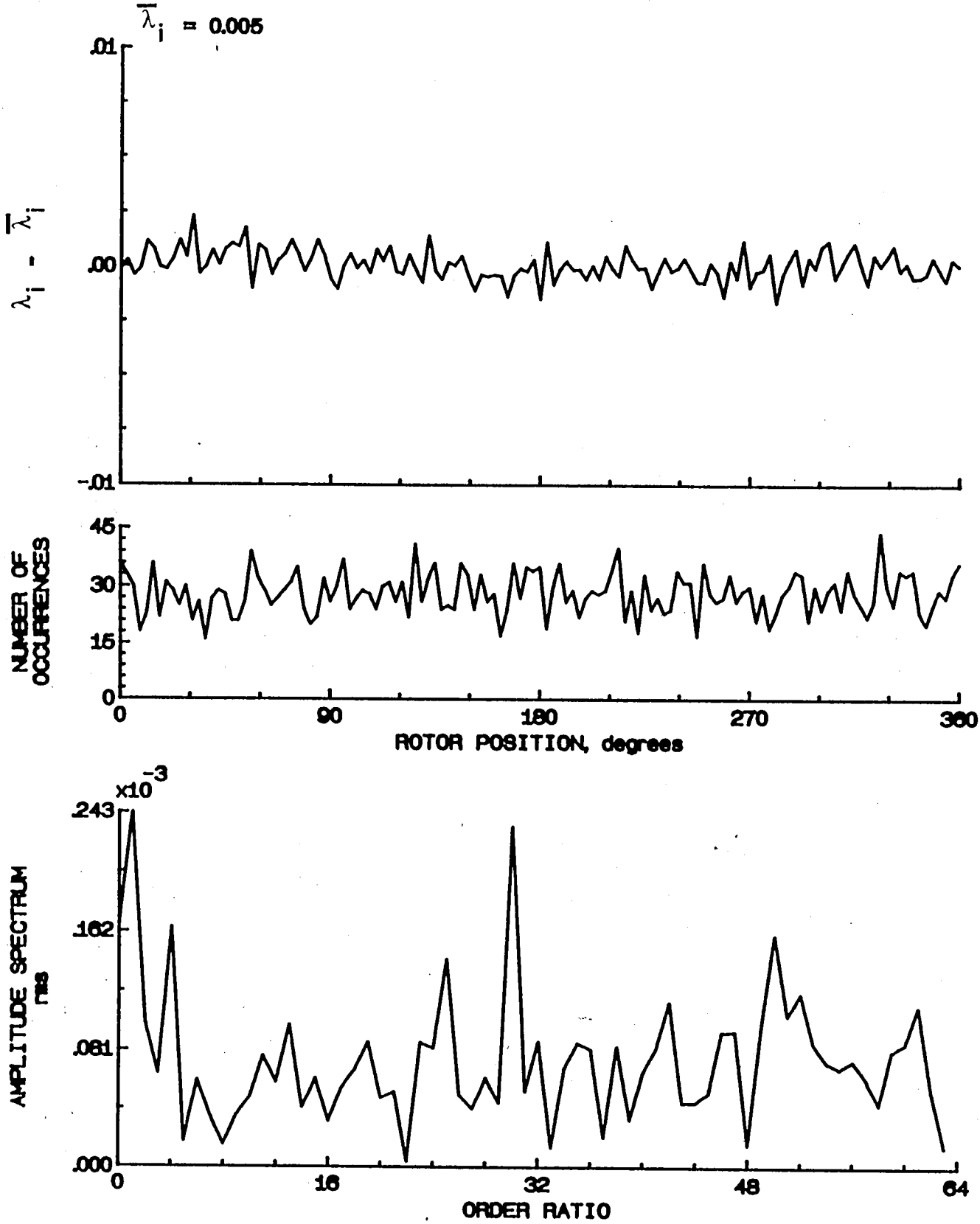


Figure 87.- Induced inflow velocity measured at 120 degrees and r/R of 1.10.



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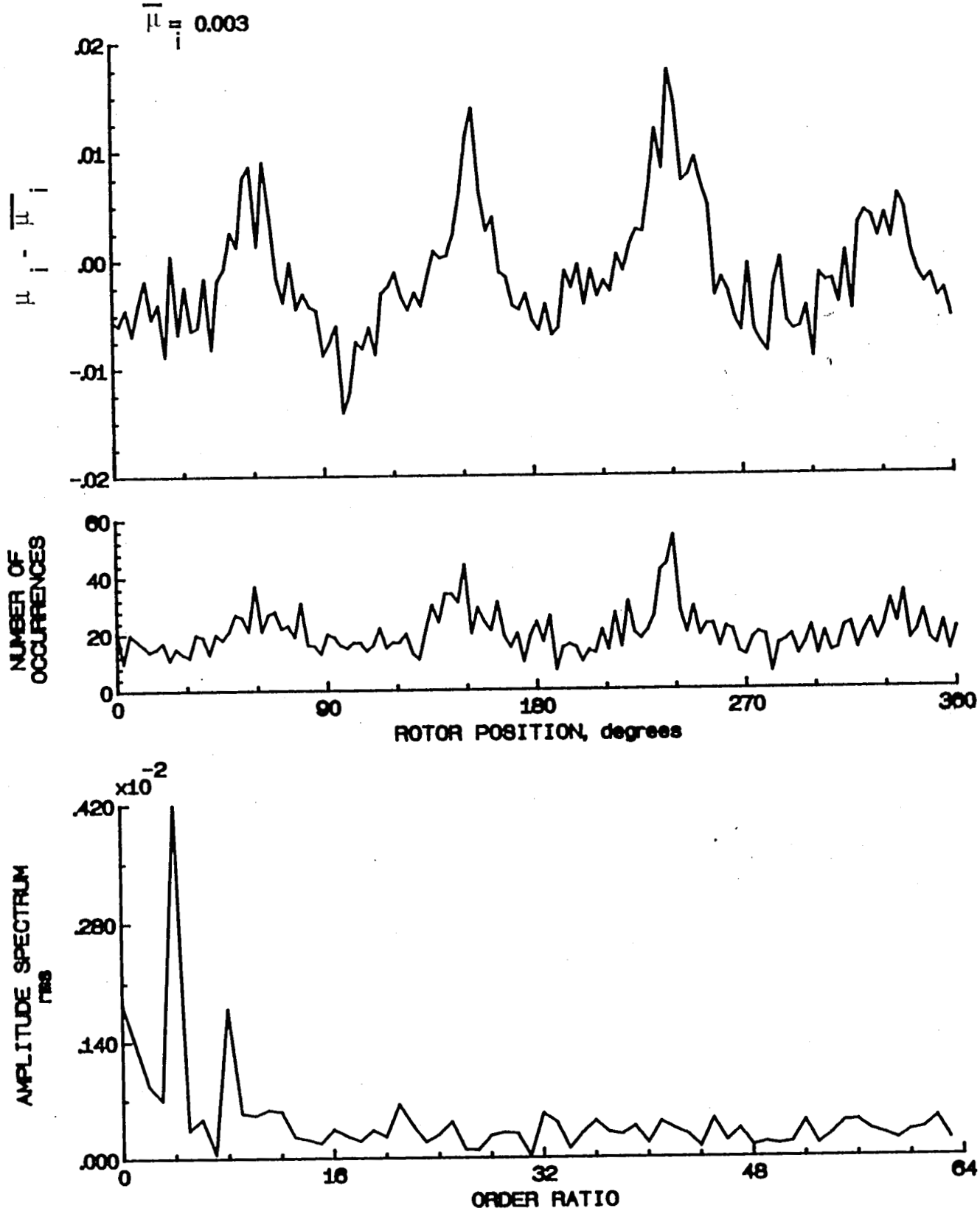
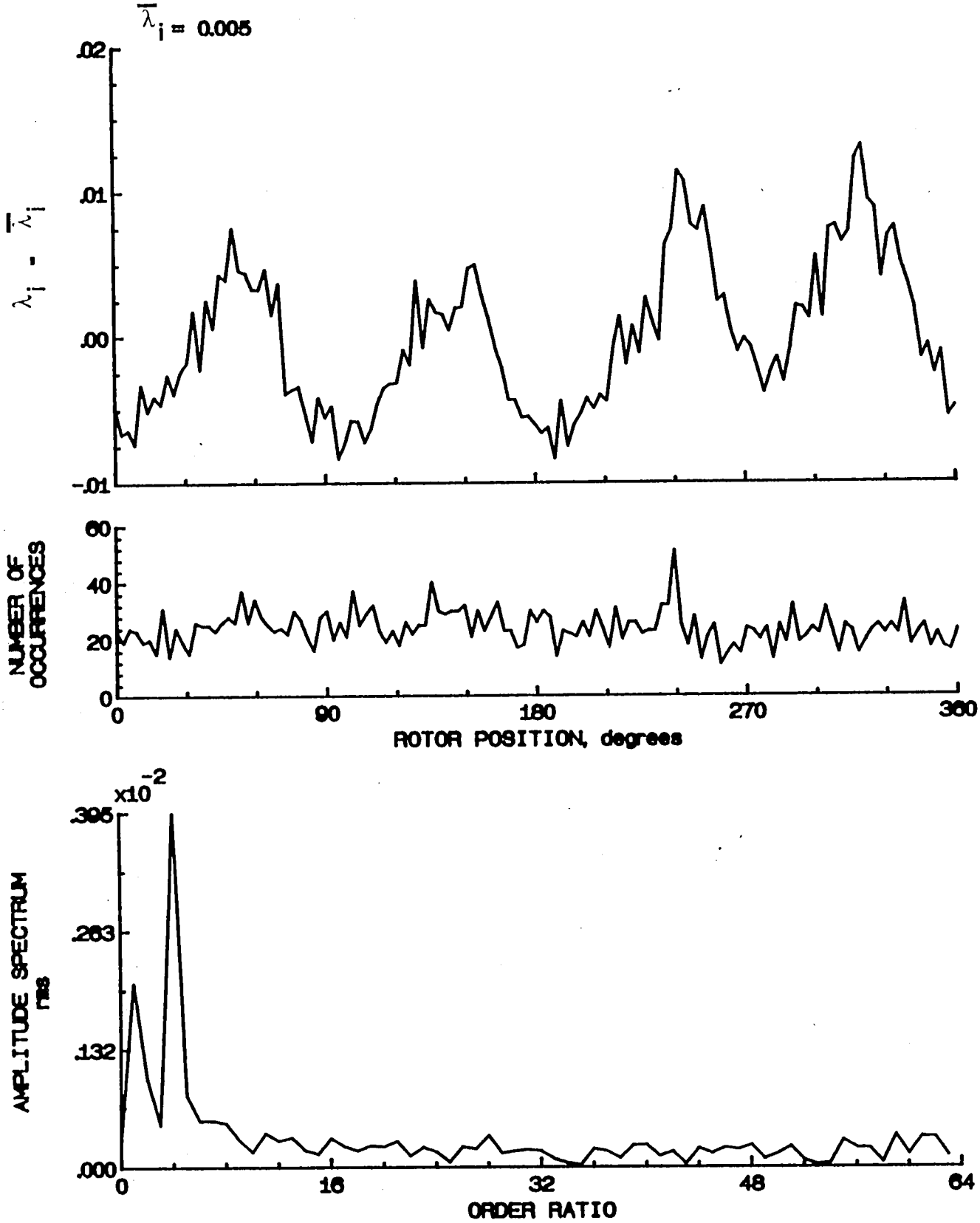


Figure 88.- Induced inflow velocity measured at 150 degrees and r/R of 0.20.



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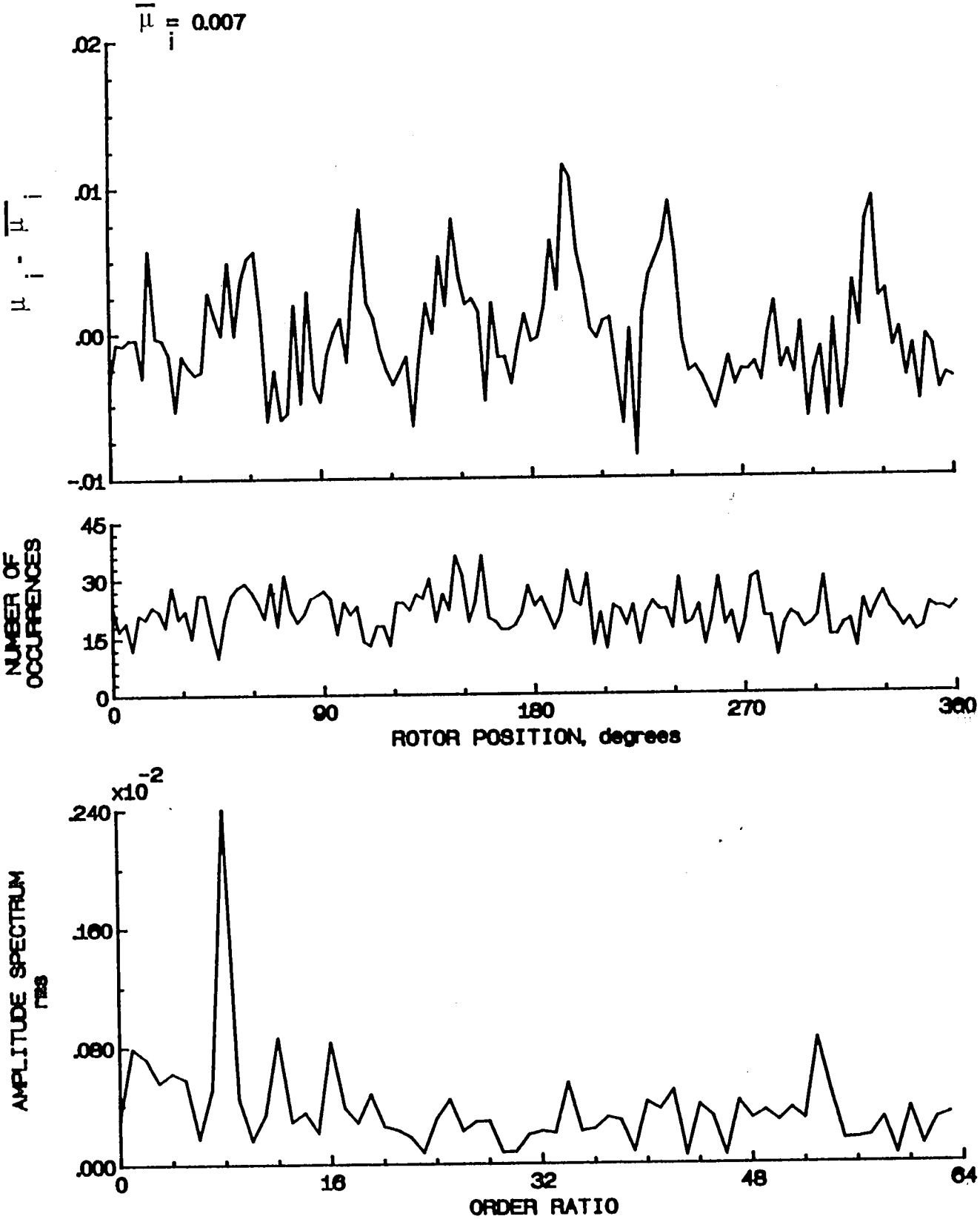


Figure 89.- Induced inflow velocity measured at 150 degrees and r/R of 0.40.

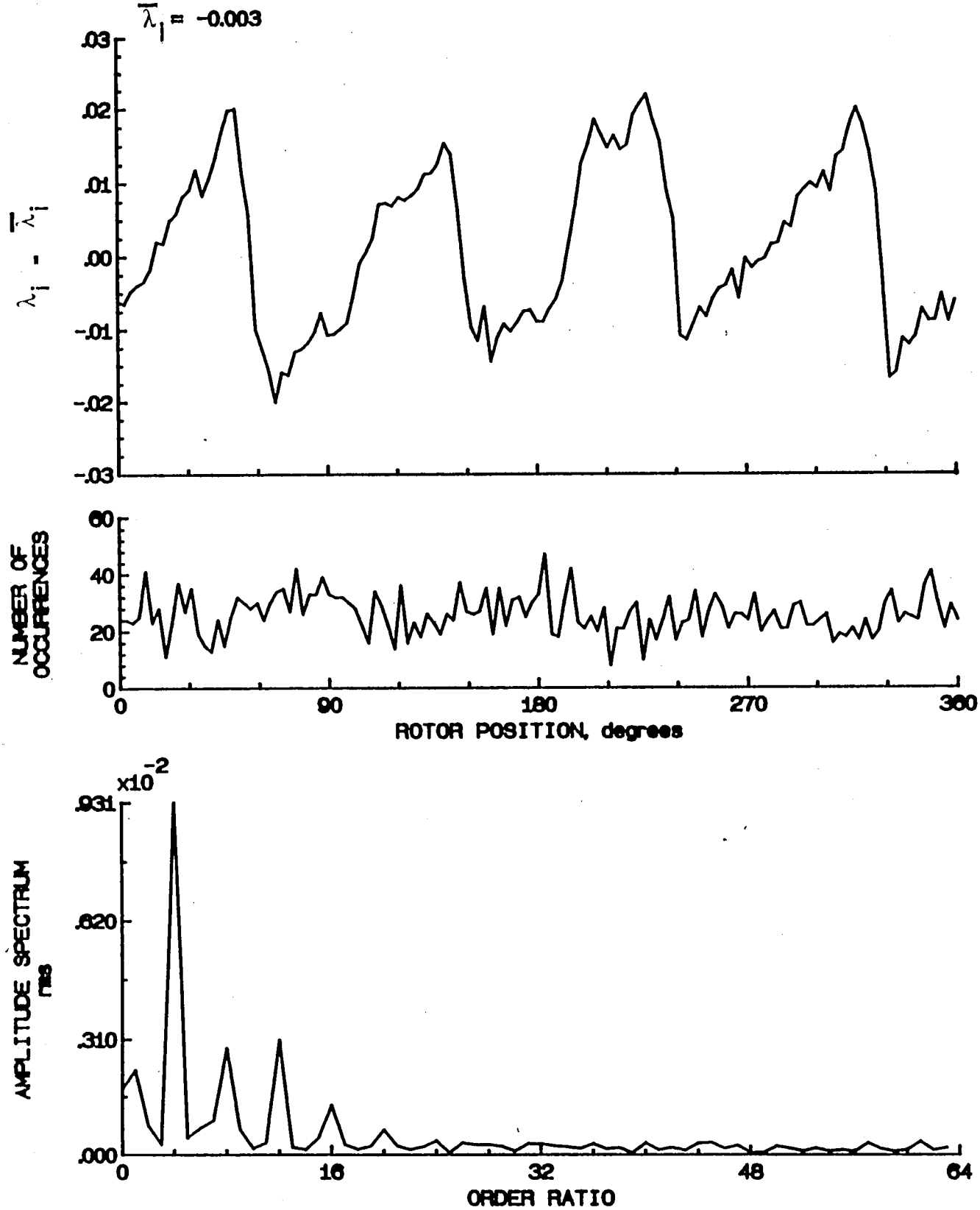


Figure 89.- Concluded.

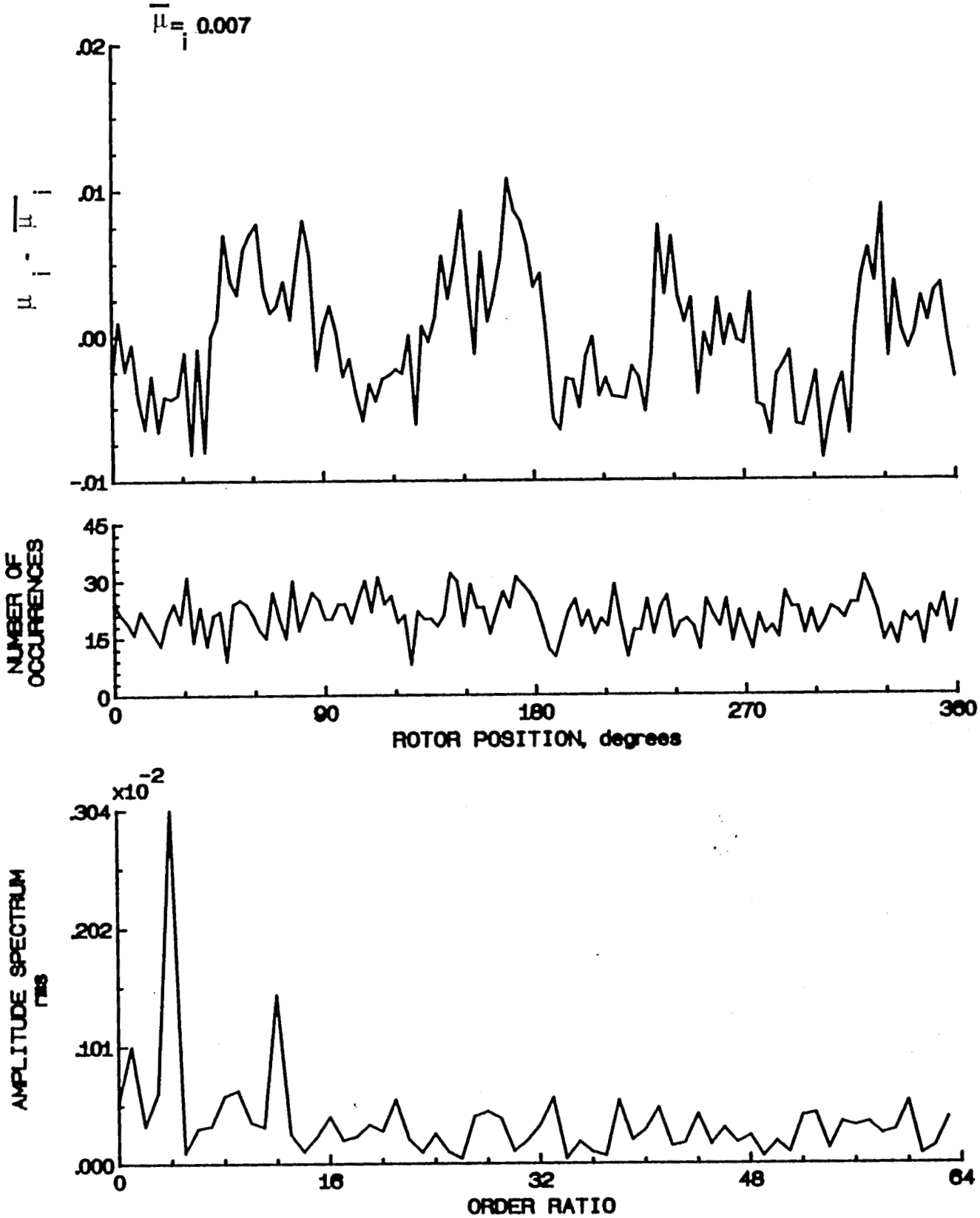
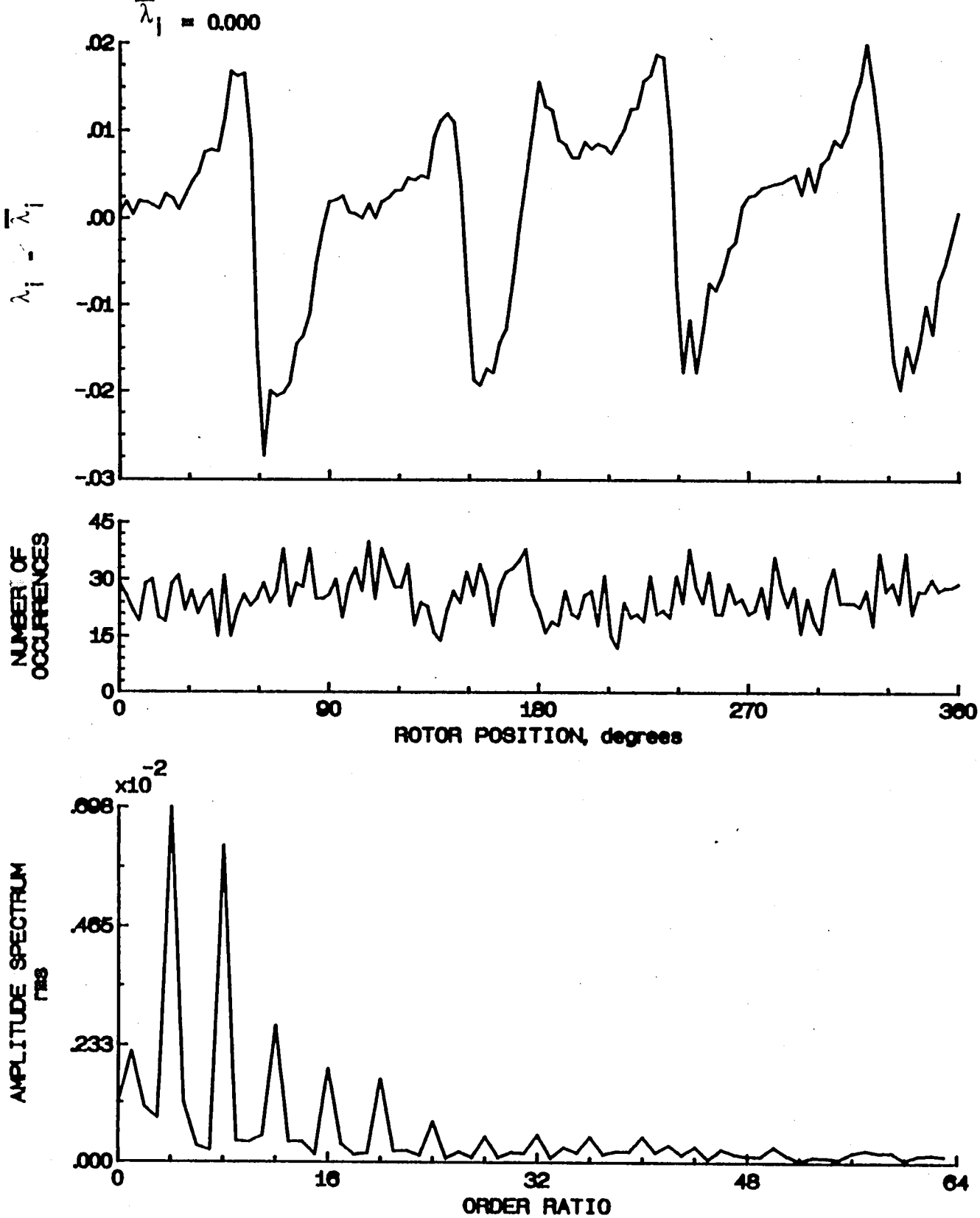


Figure 90.- Induced inflow velocity measured at 150 degrees and r/R of 0.50.



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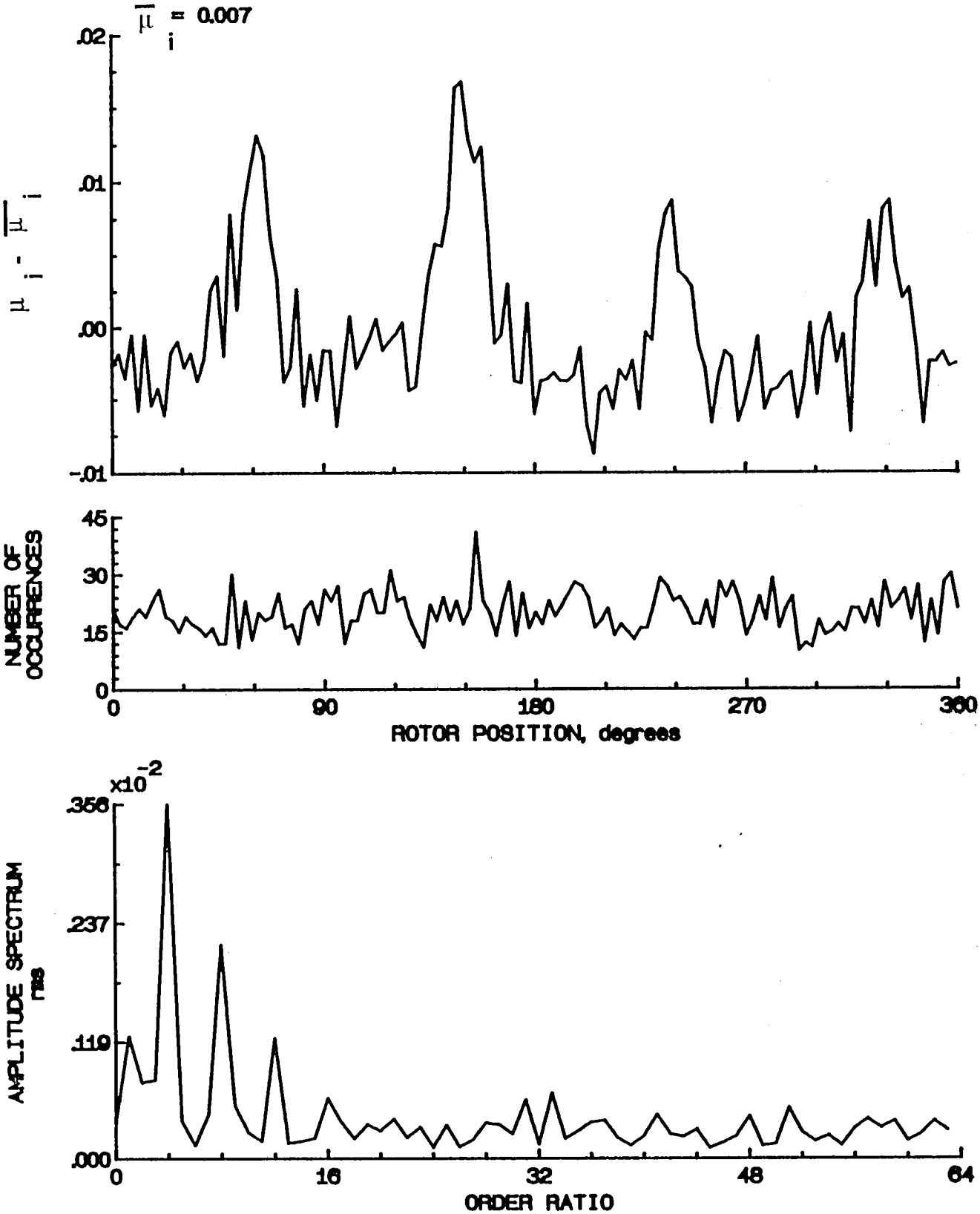
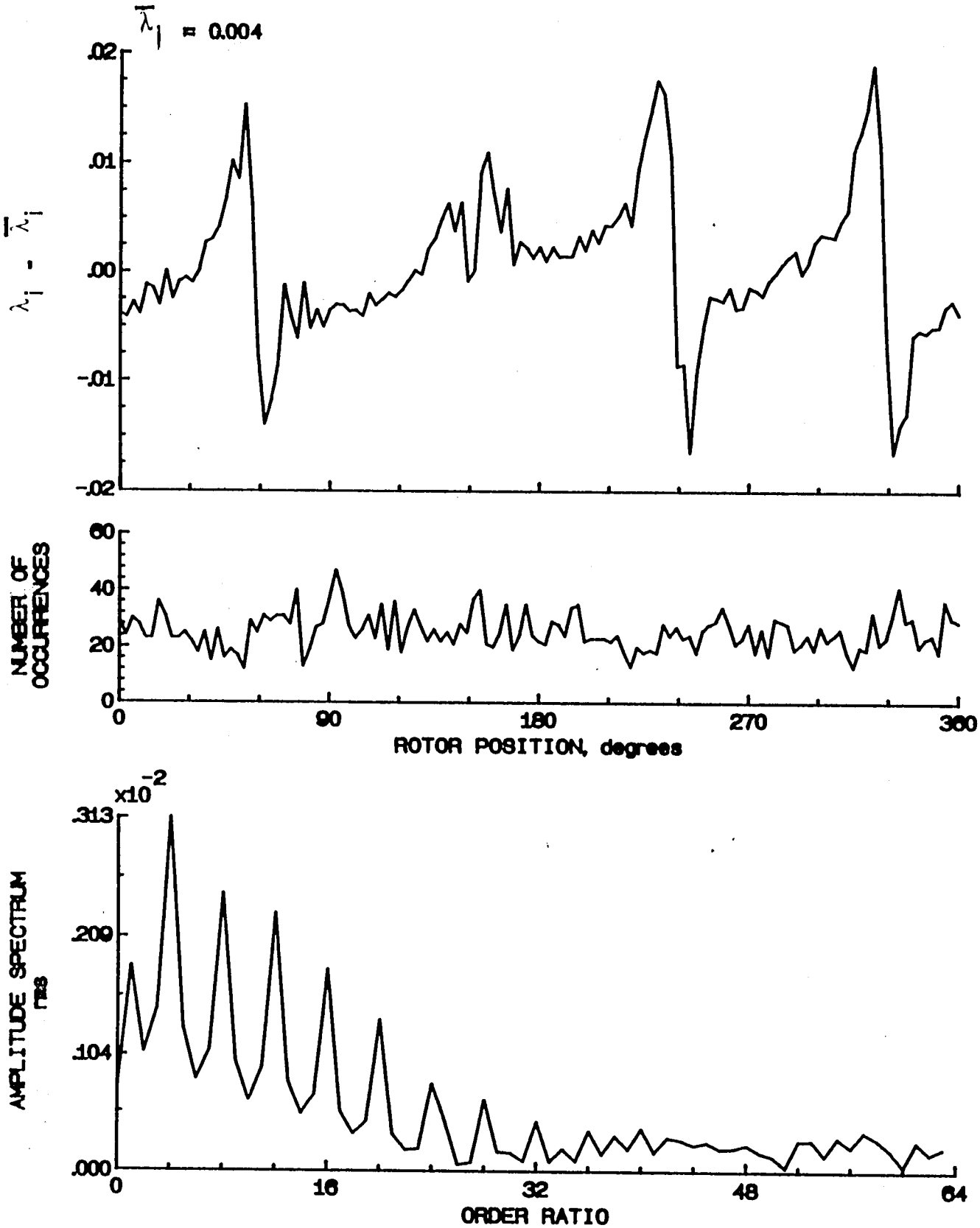


Figure 91.- Induced inflow velocity measured at 150 degrees and r/R of 0.60.



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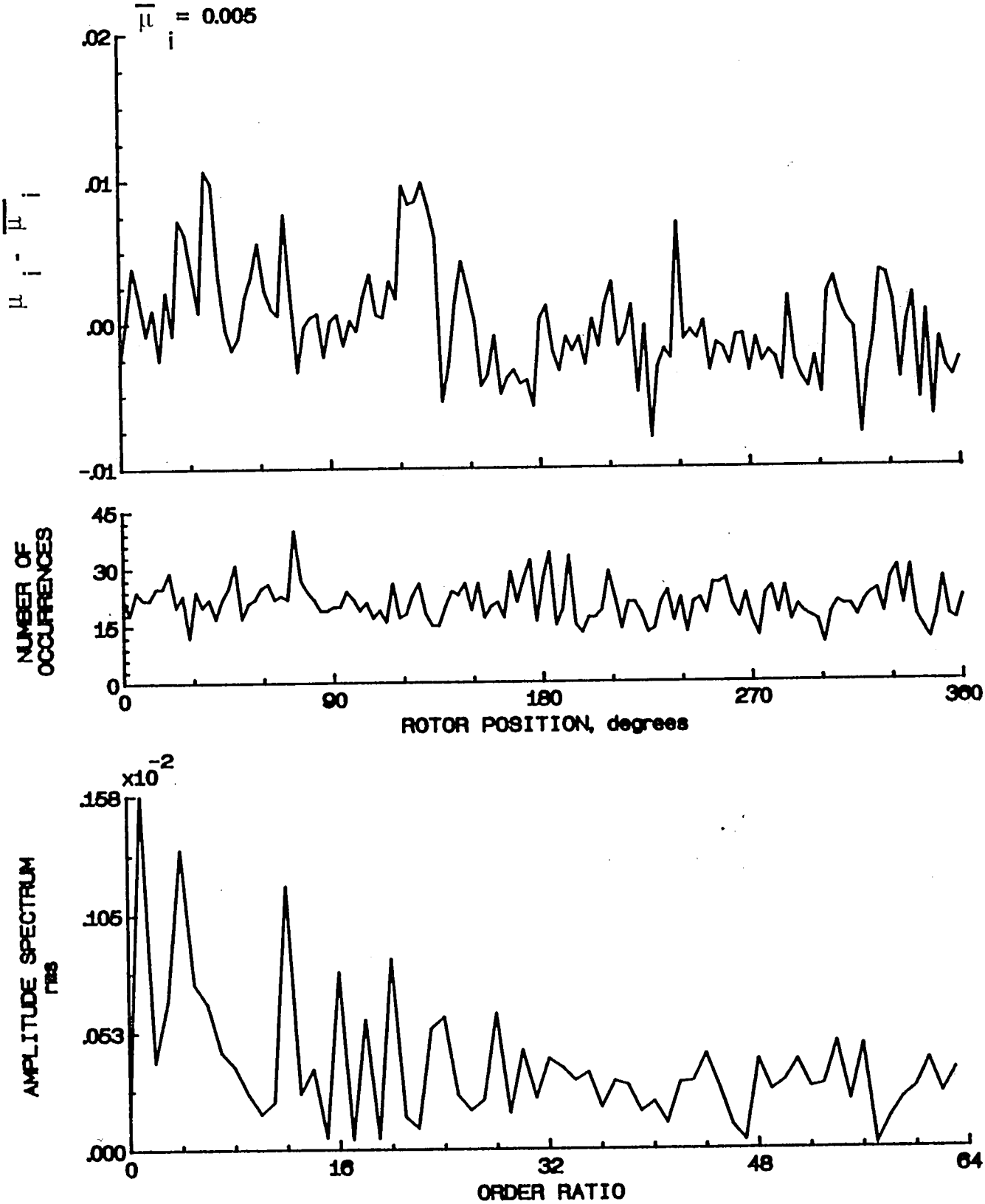
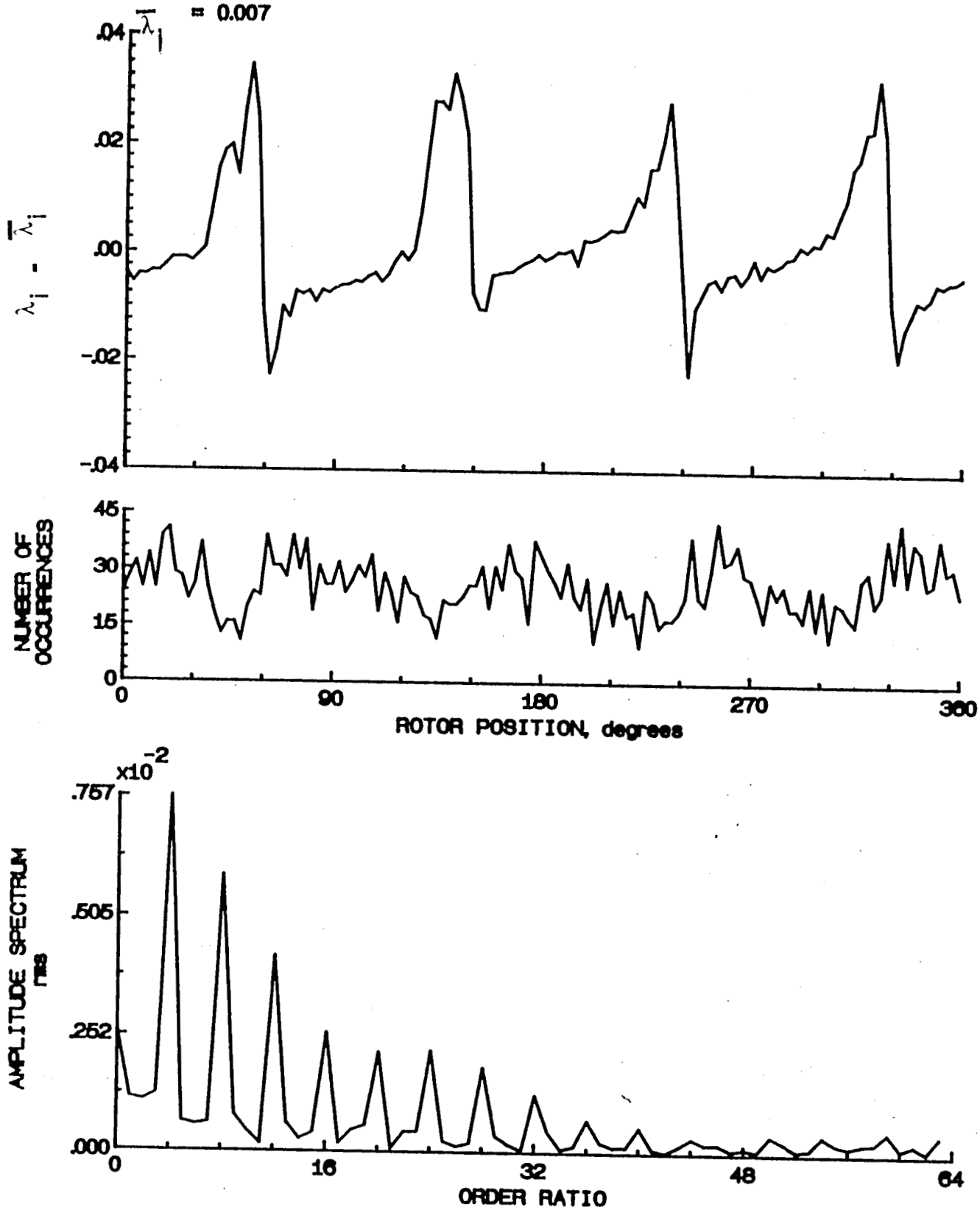


Figure 92.- Induced inflow velocity measured at 150 degrees and r/R of 0.70.



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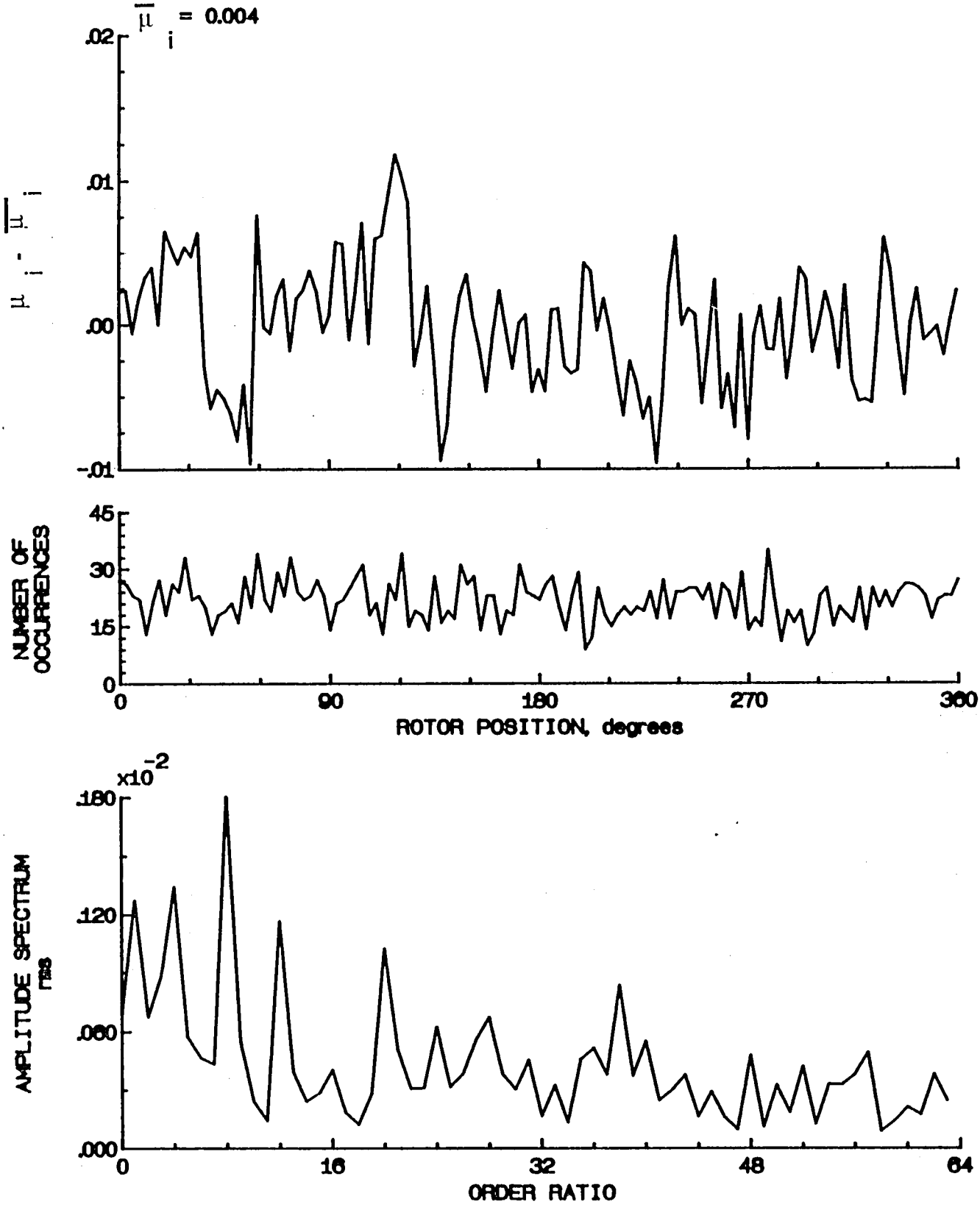
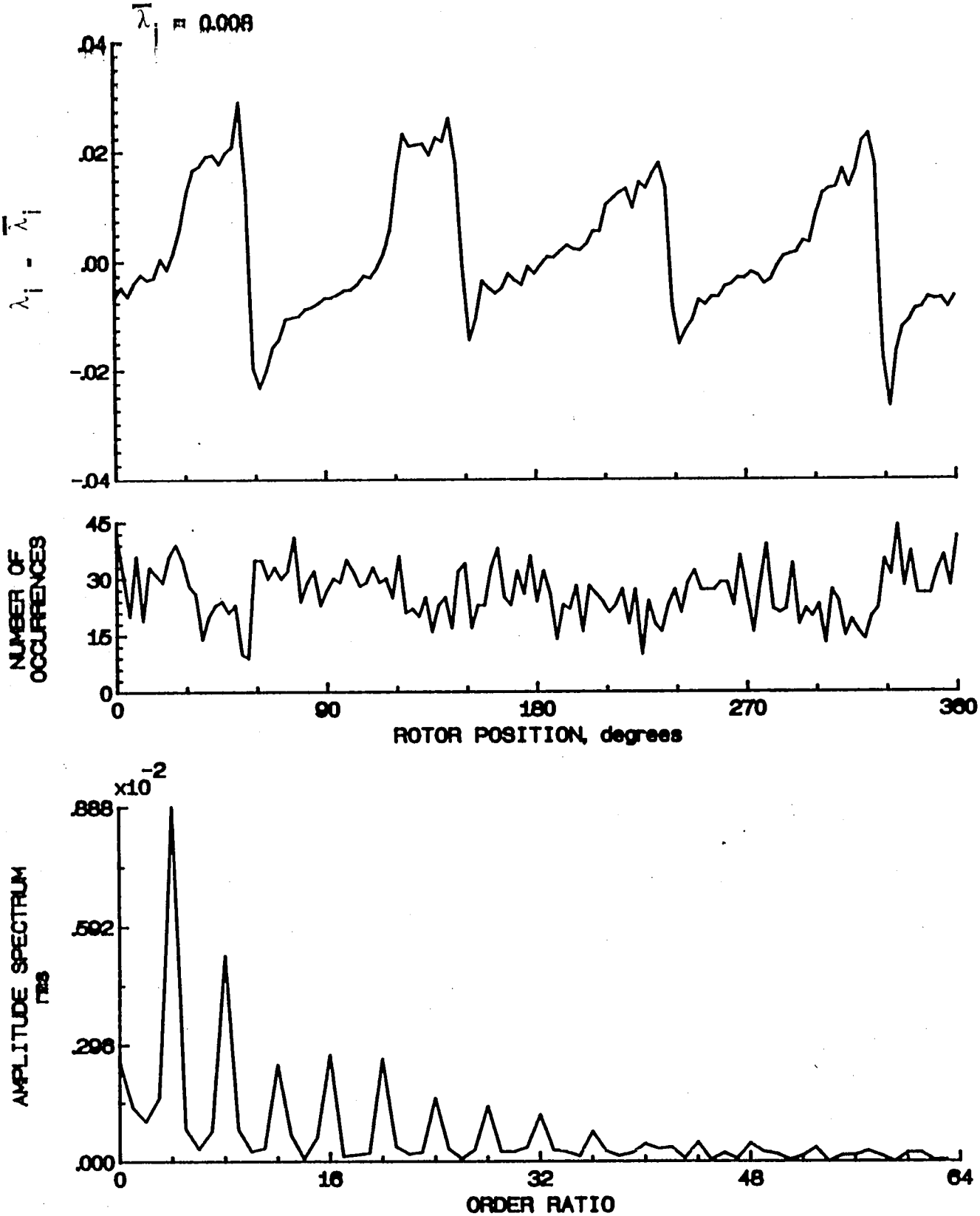


Figure 93.- Induced inflow velocity measured at 150 degrees and r/R of 0.74.



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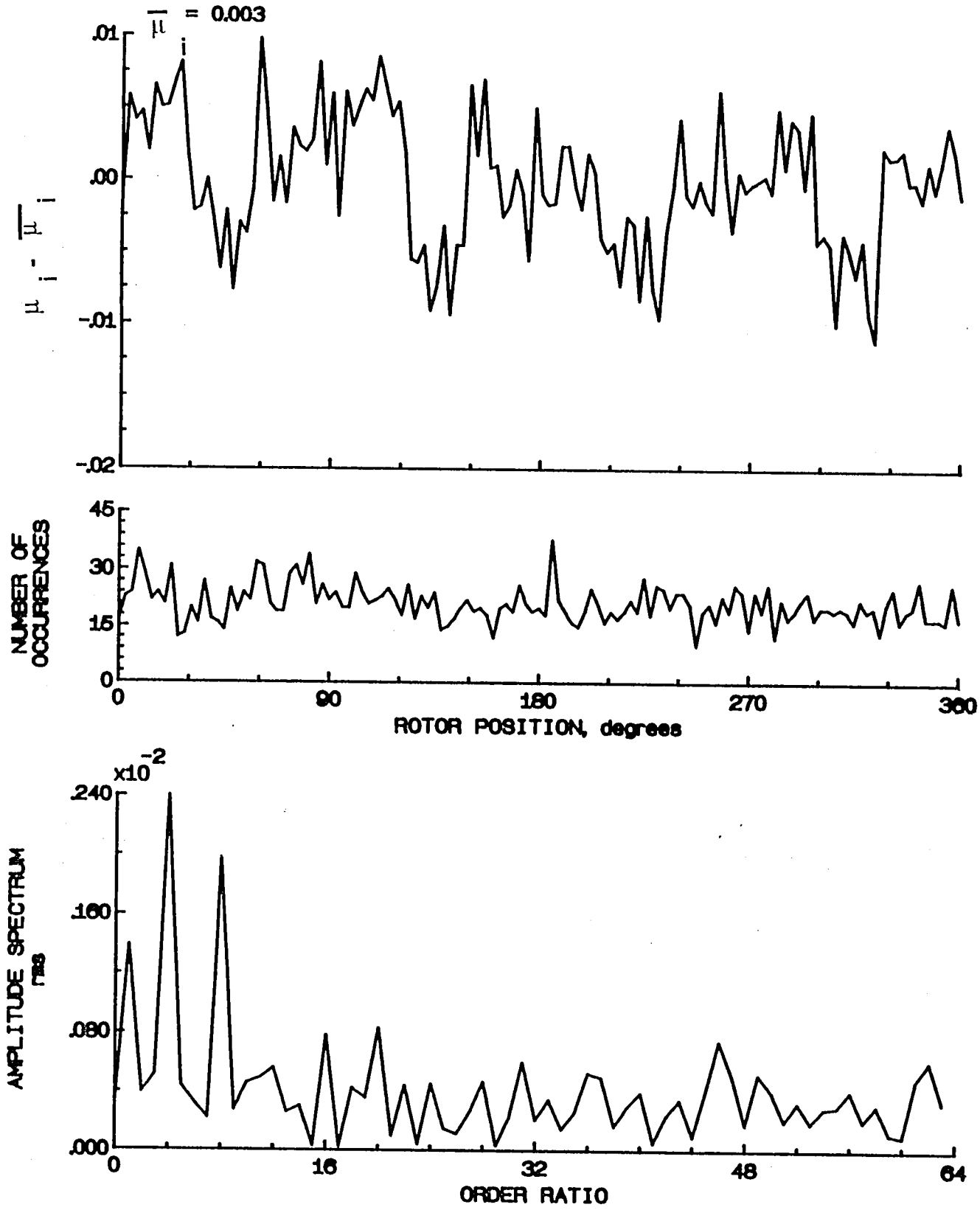
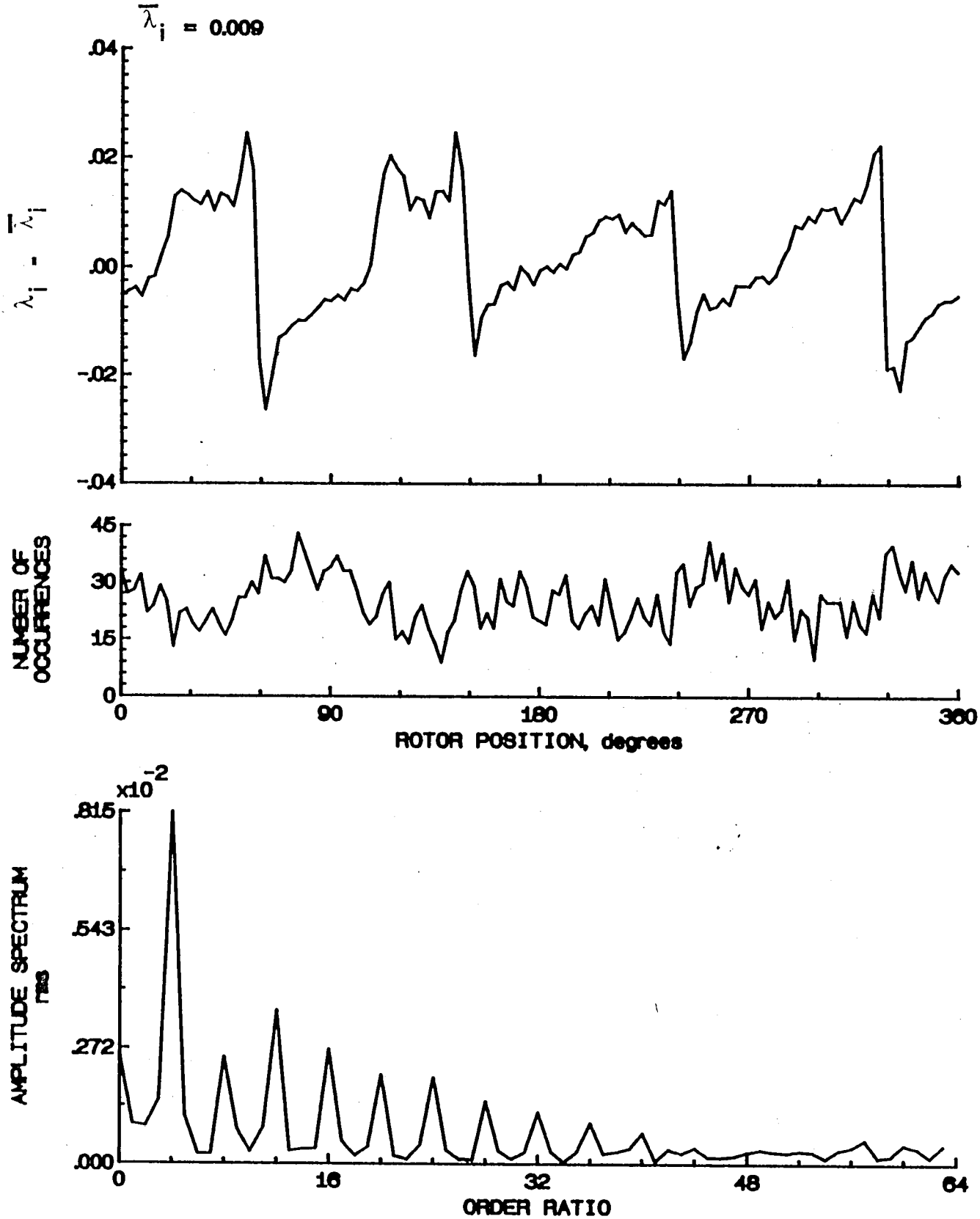


Figure 94.- Induced inflow velocity measured at 150 degrees and r/R of 0.78.



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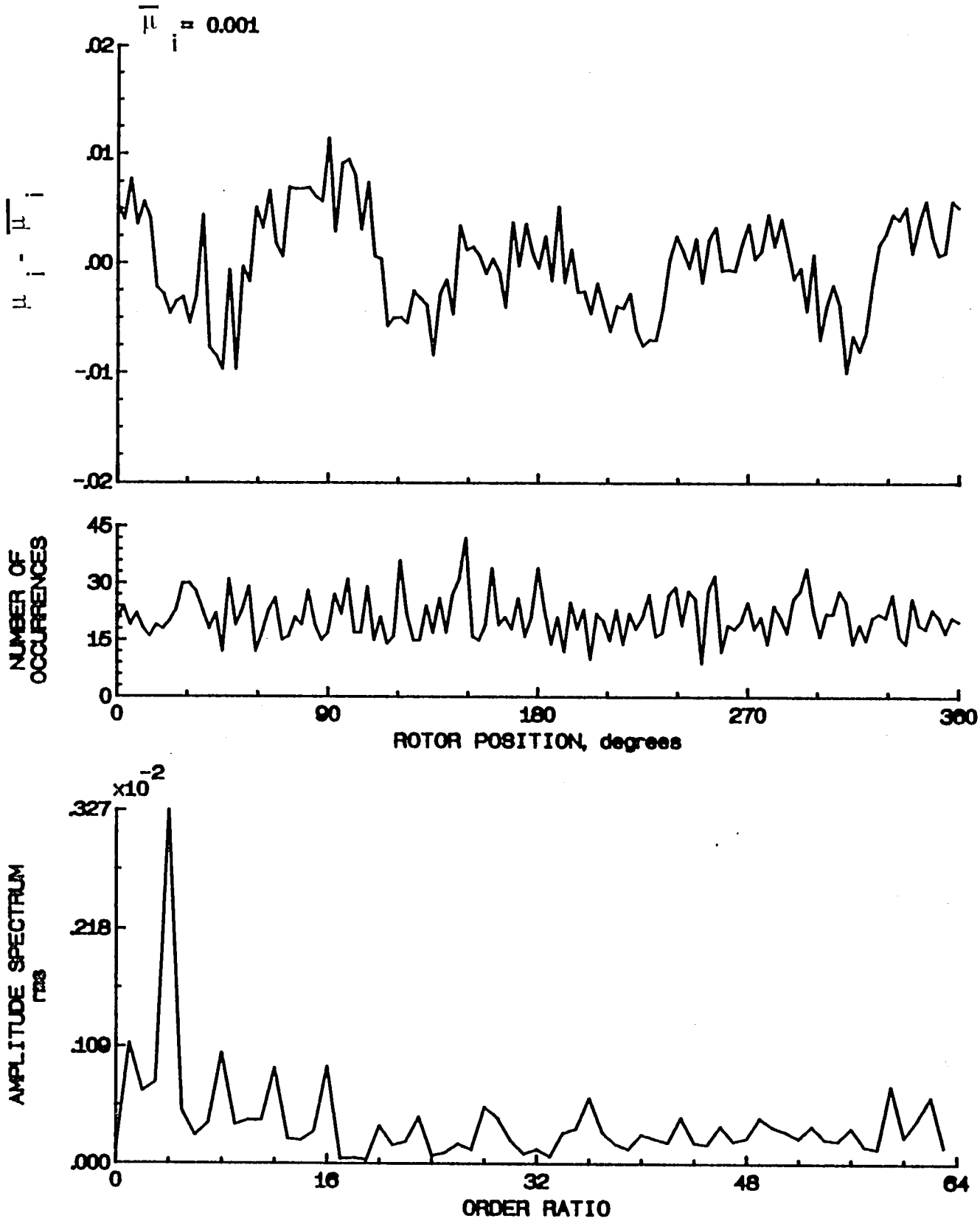
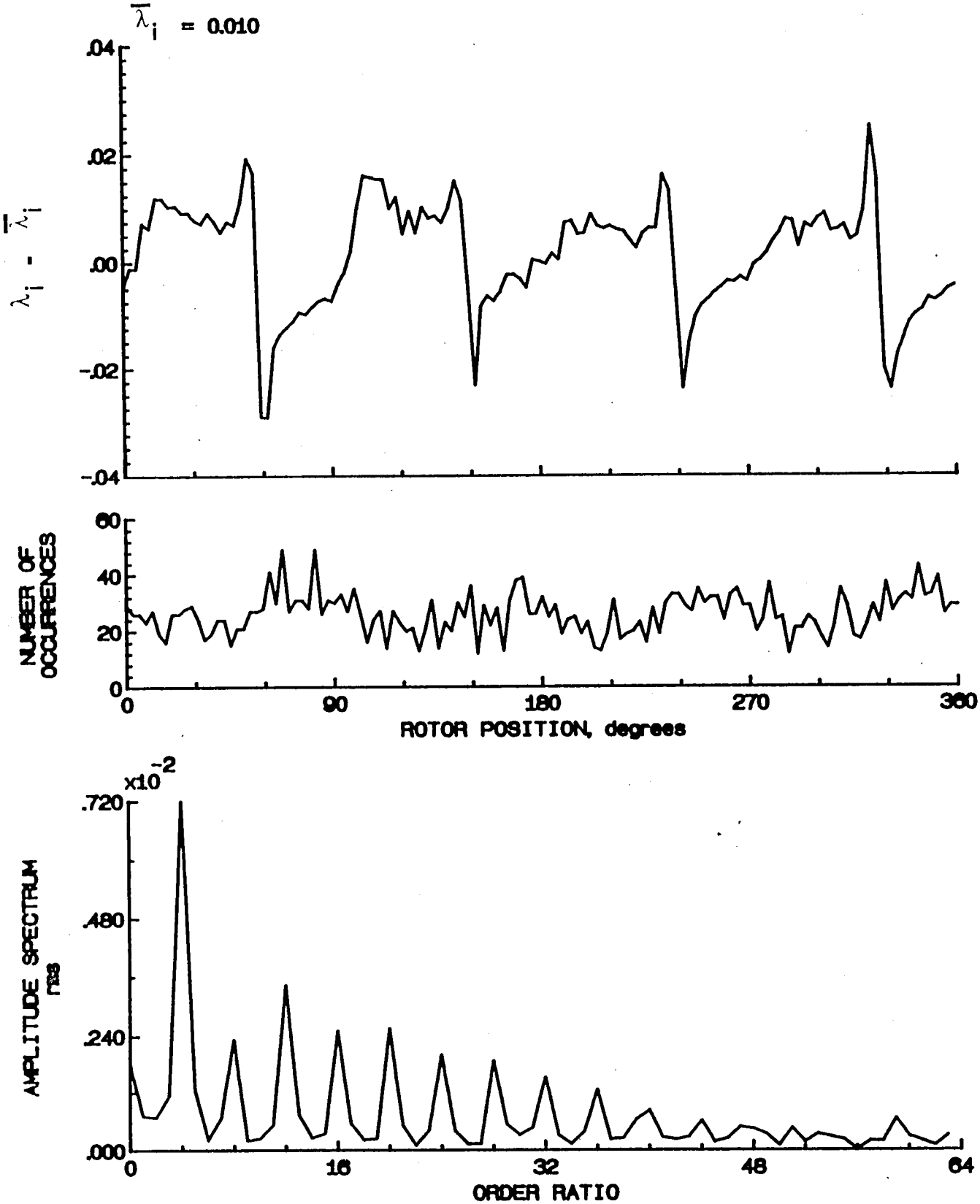


Figure 95.- Induced inflow velocity measured at 150 degrees and r/R of 0.82.



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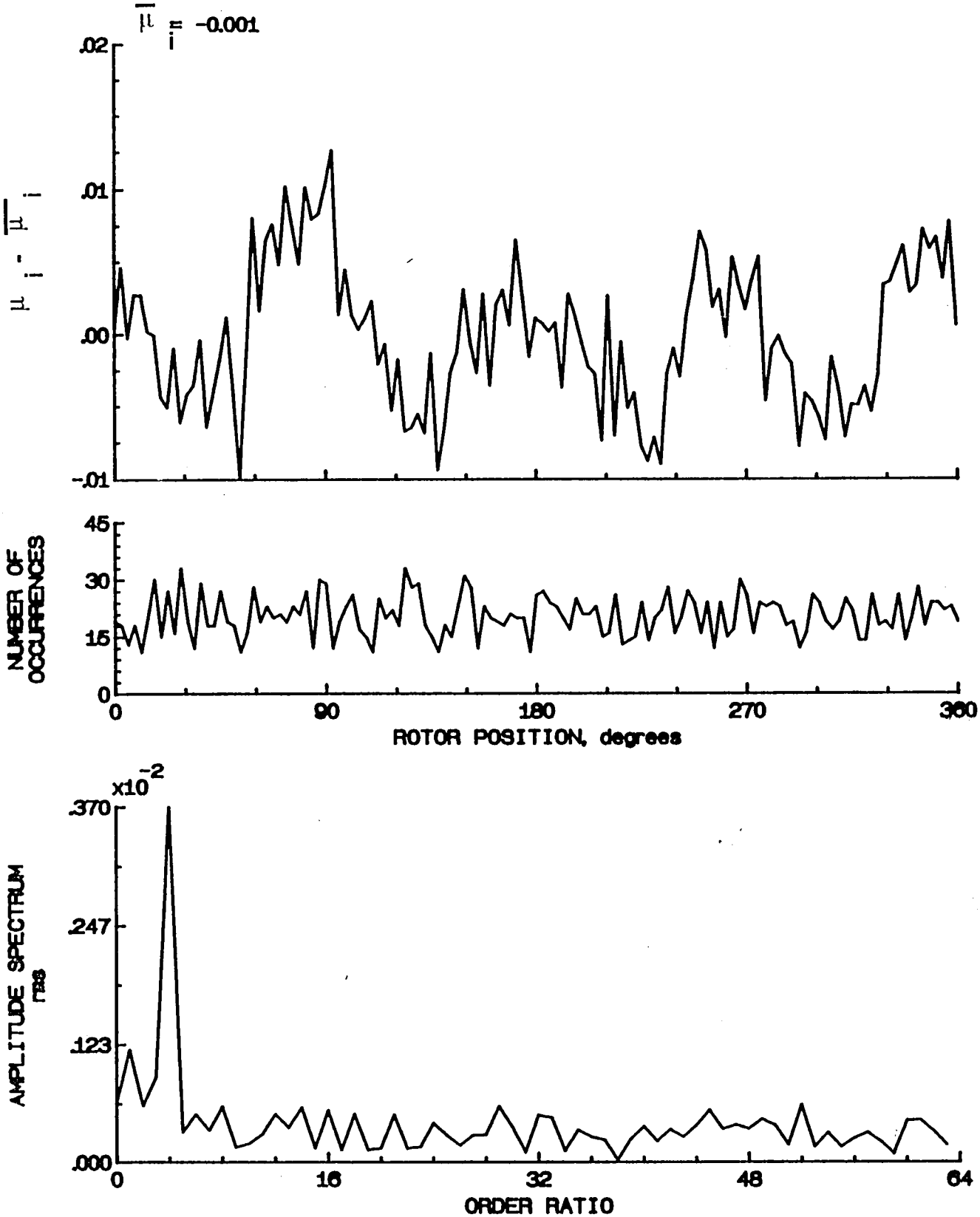
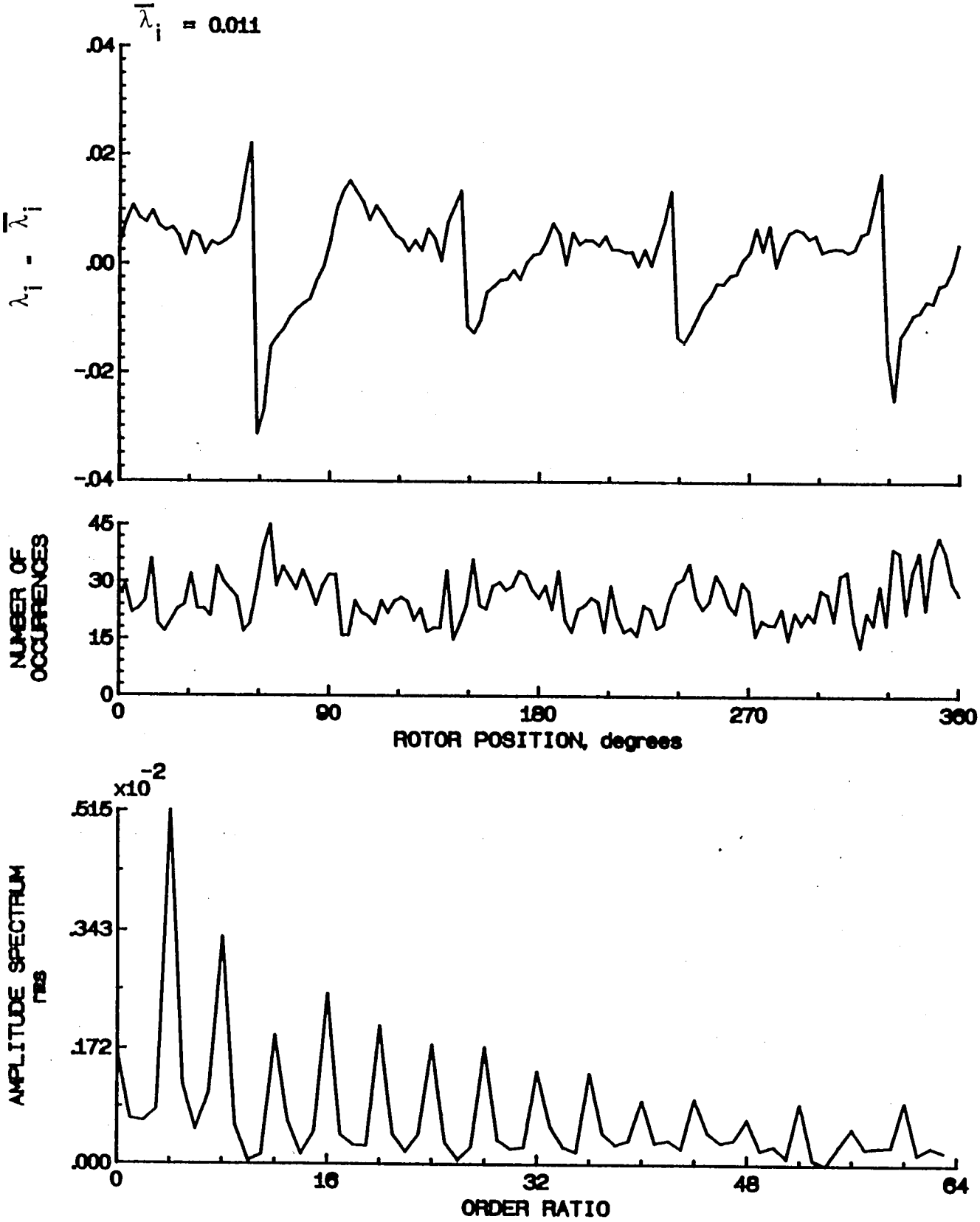


Figure 96.- Induced inflow velocity measured at 150 degrees and r/R of 0.86.



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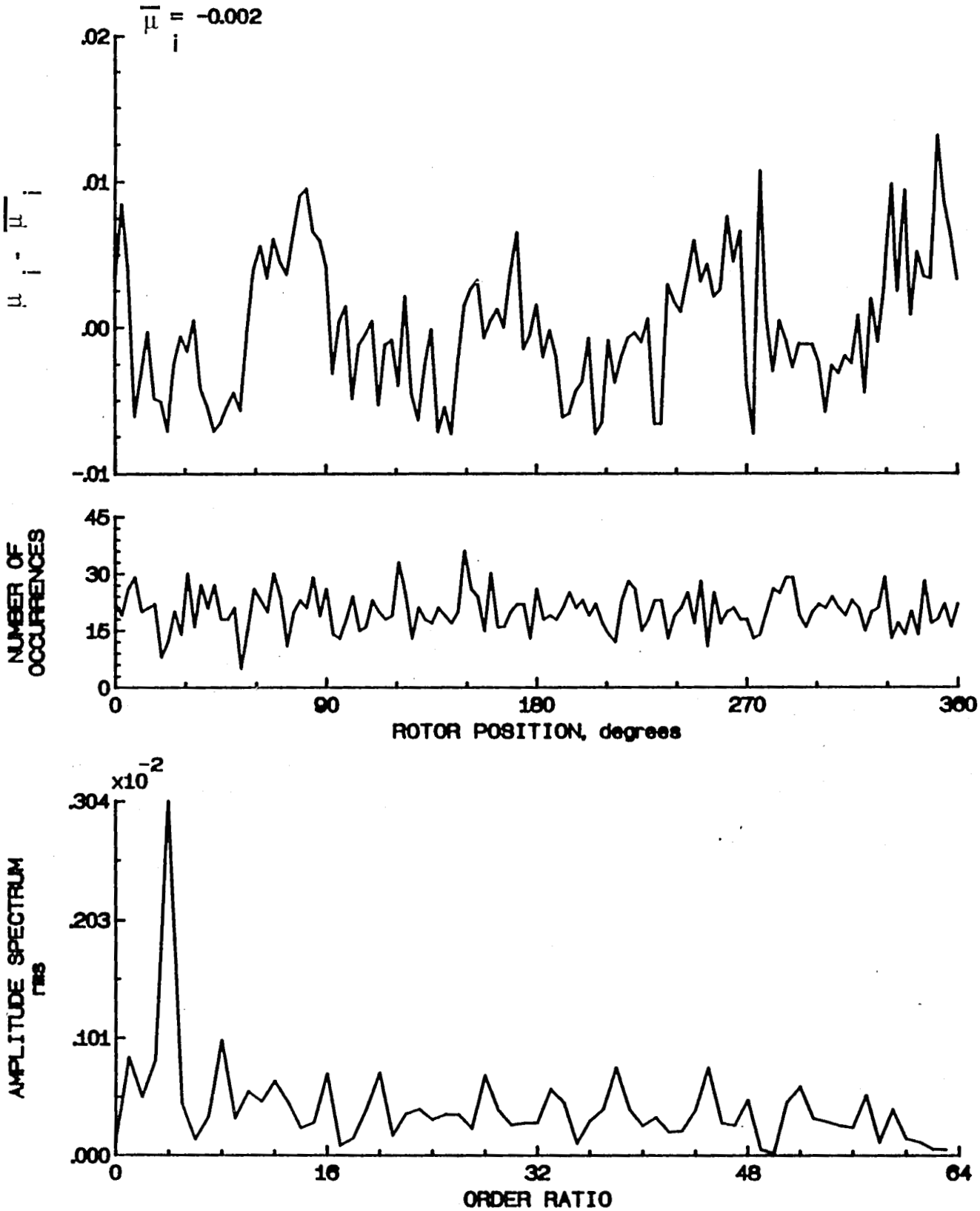
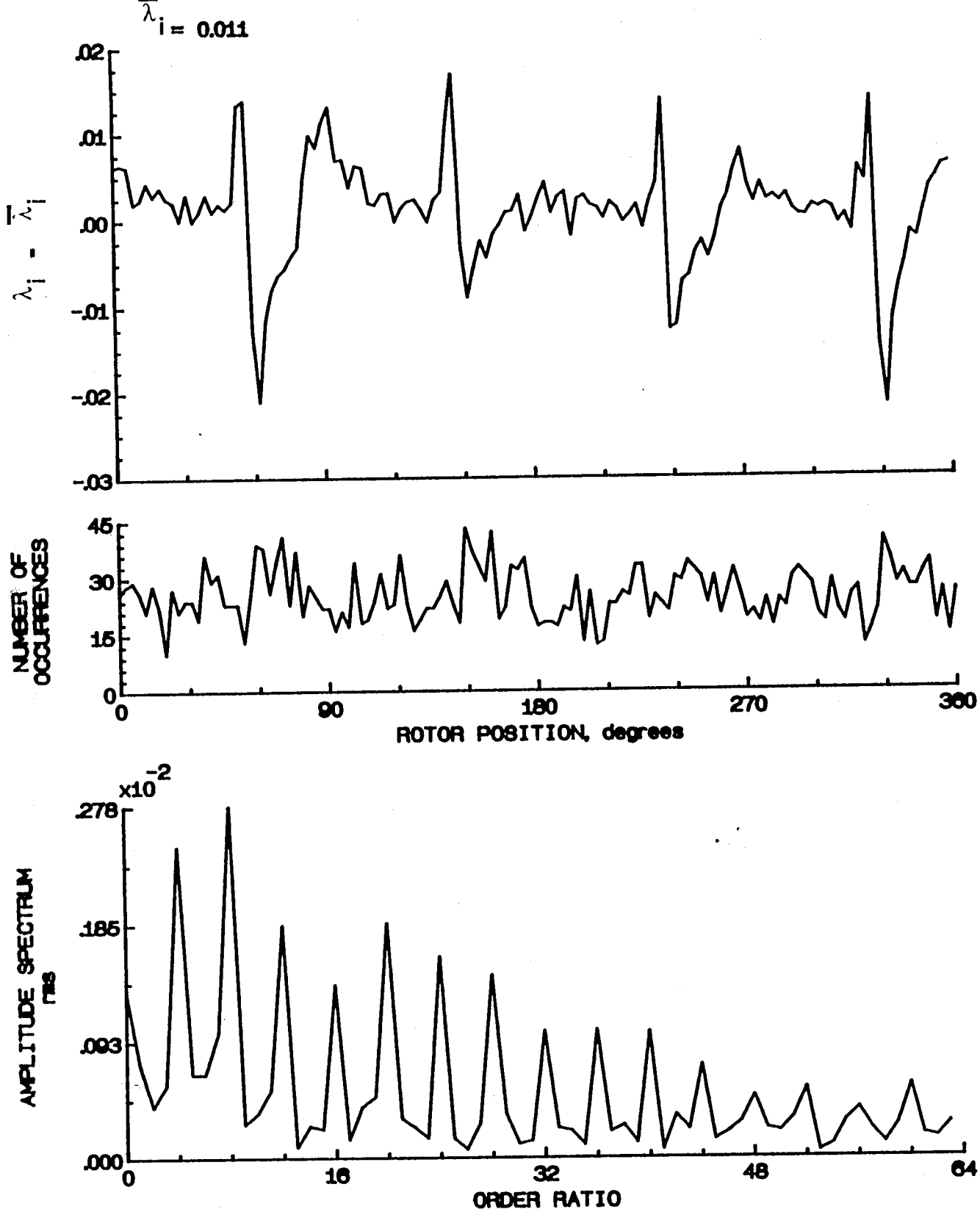


Figure 97.- Induced inflow velocity measured at 150 degrees and r/R of 0.90.



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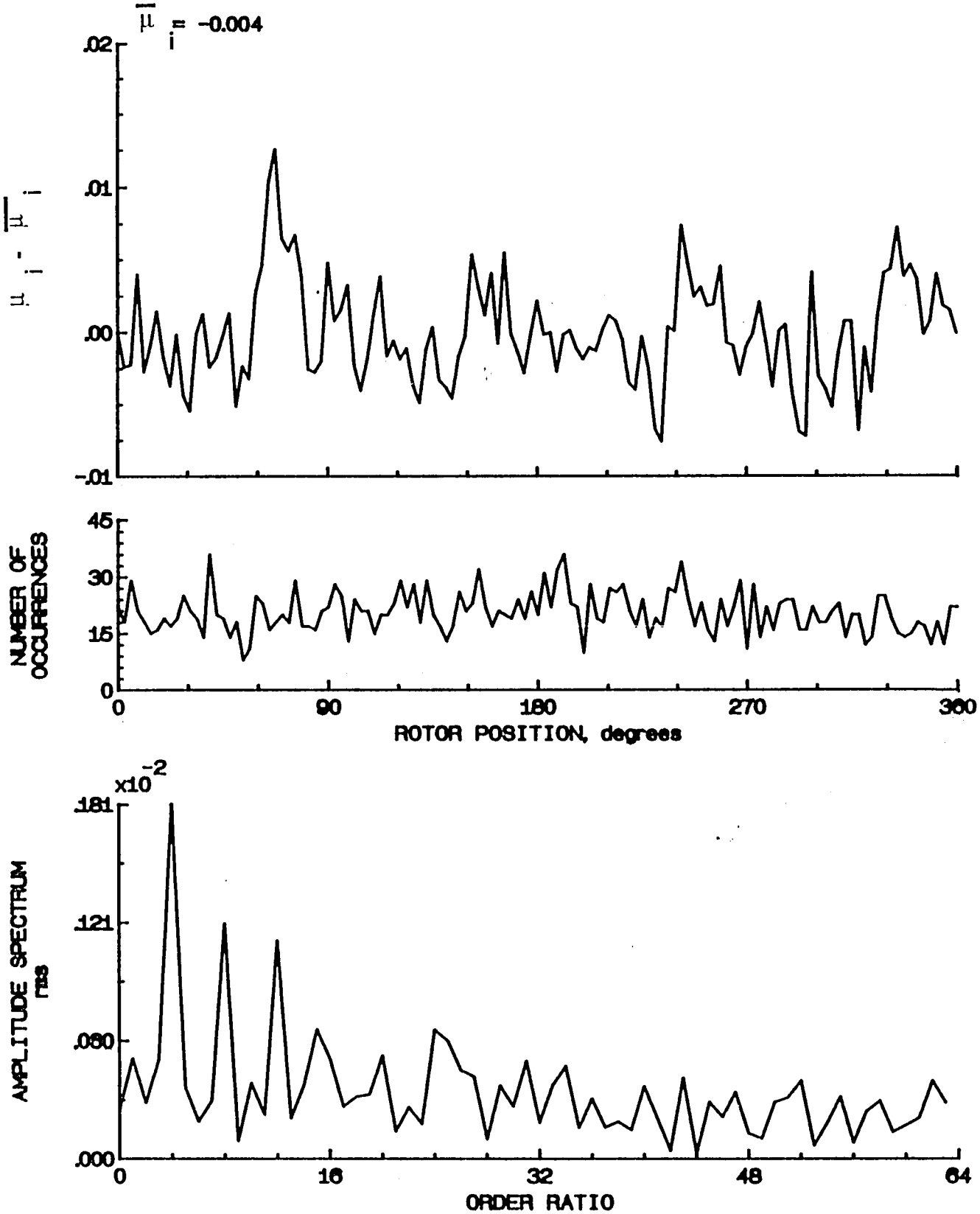
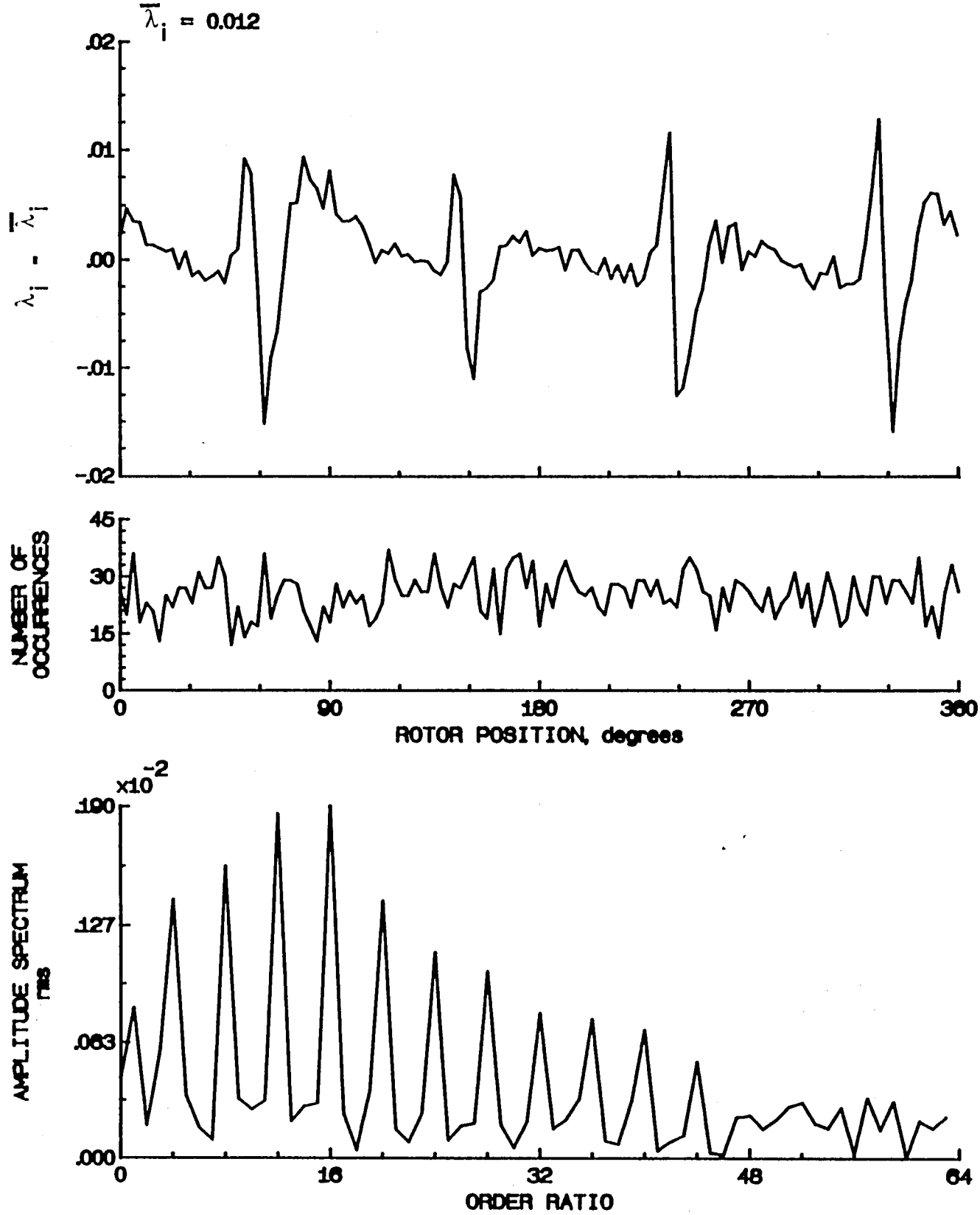


Figure 98.- Induced inflow velocity measured at 150 degrees and r/R of 0.94.



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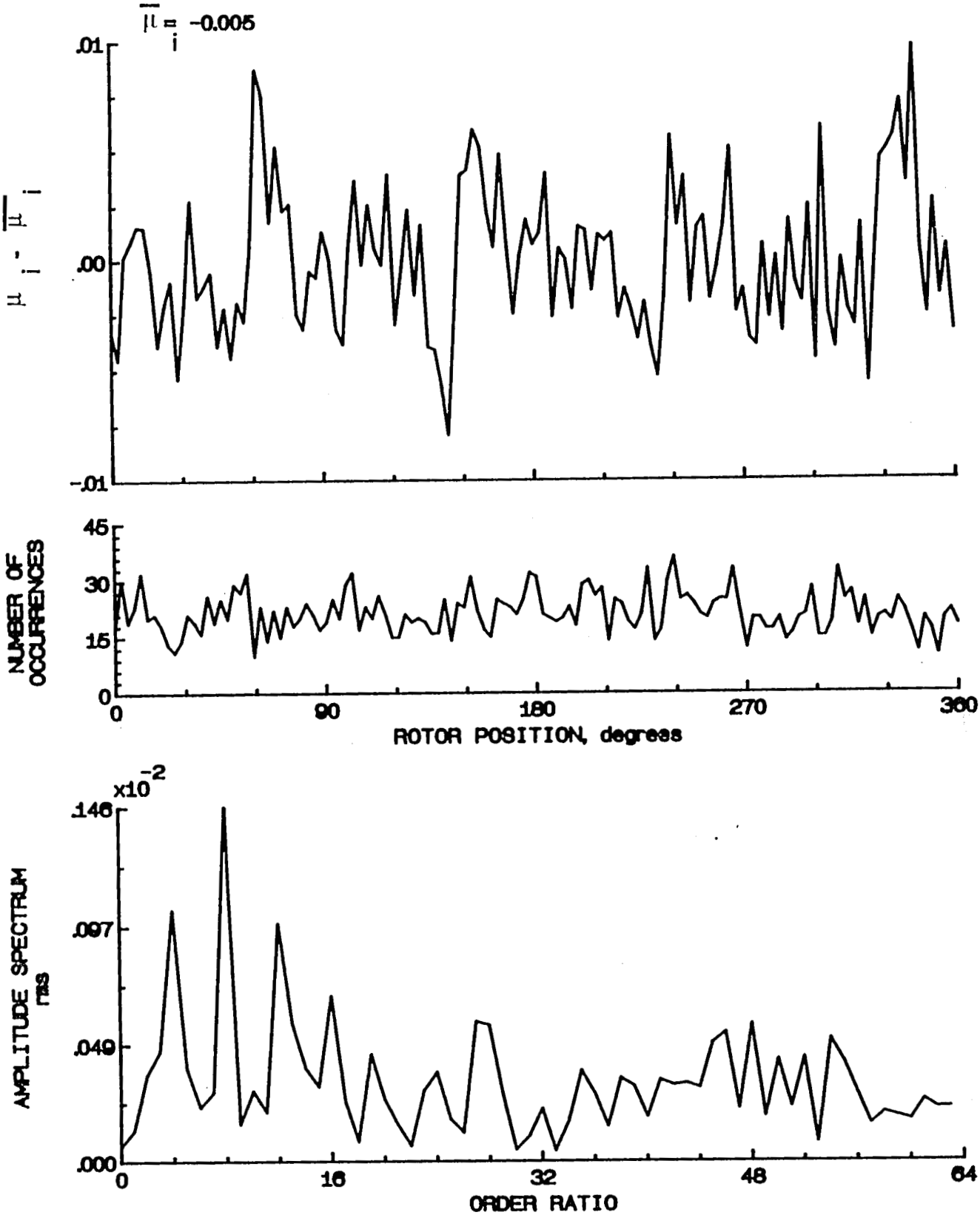
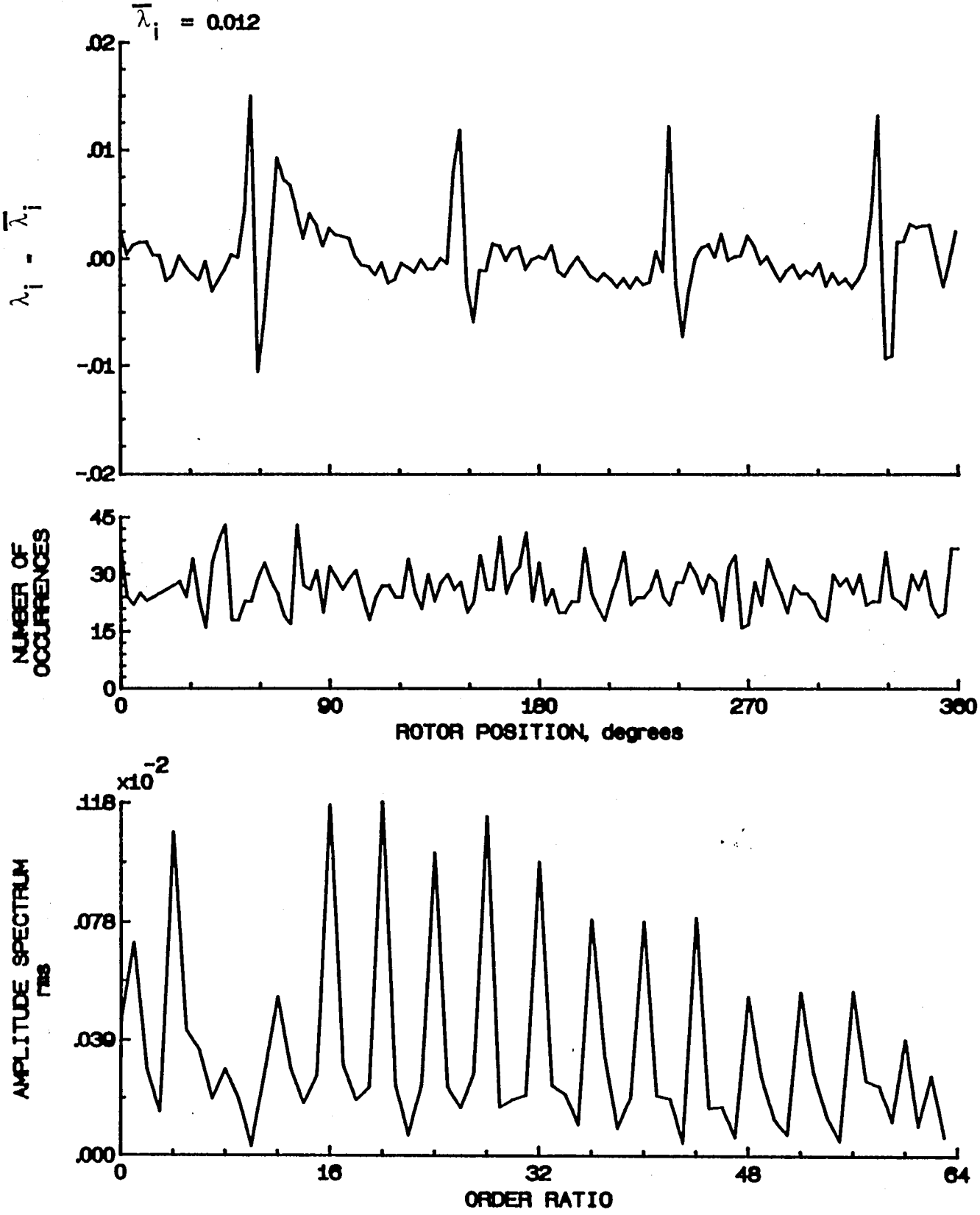


Figure 99.- Induced inflow velocity measured at 150 degrees and r/R of 0.98.



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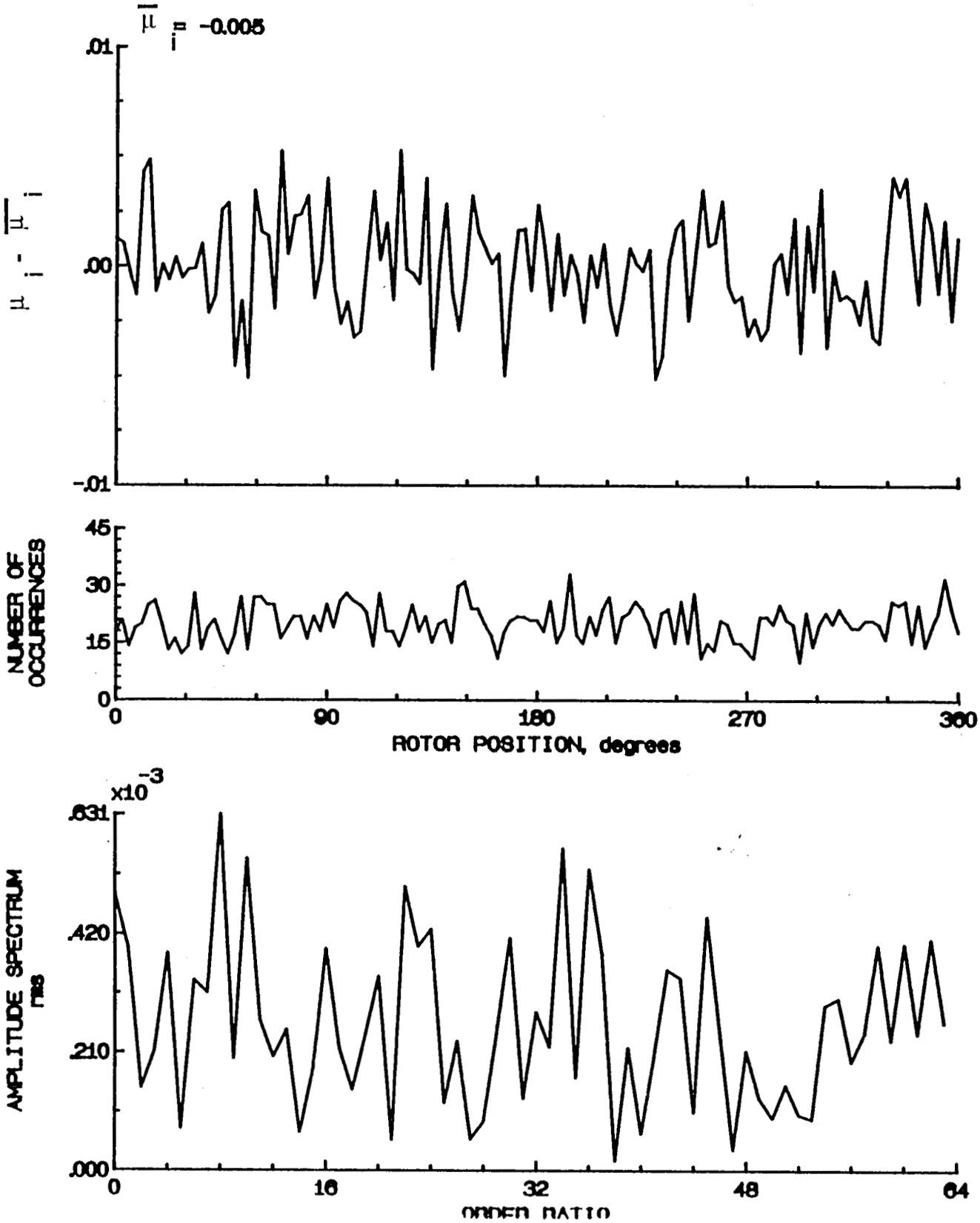


Figure 100.- Induced inflow velocity measured at 150 degrees and r/R of 1.02.

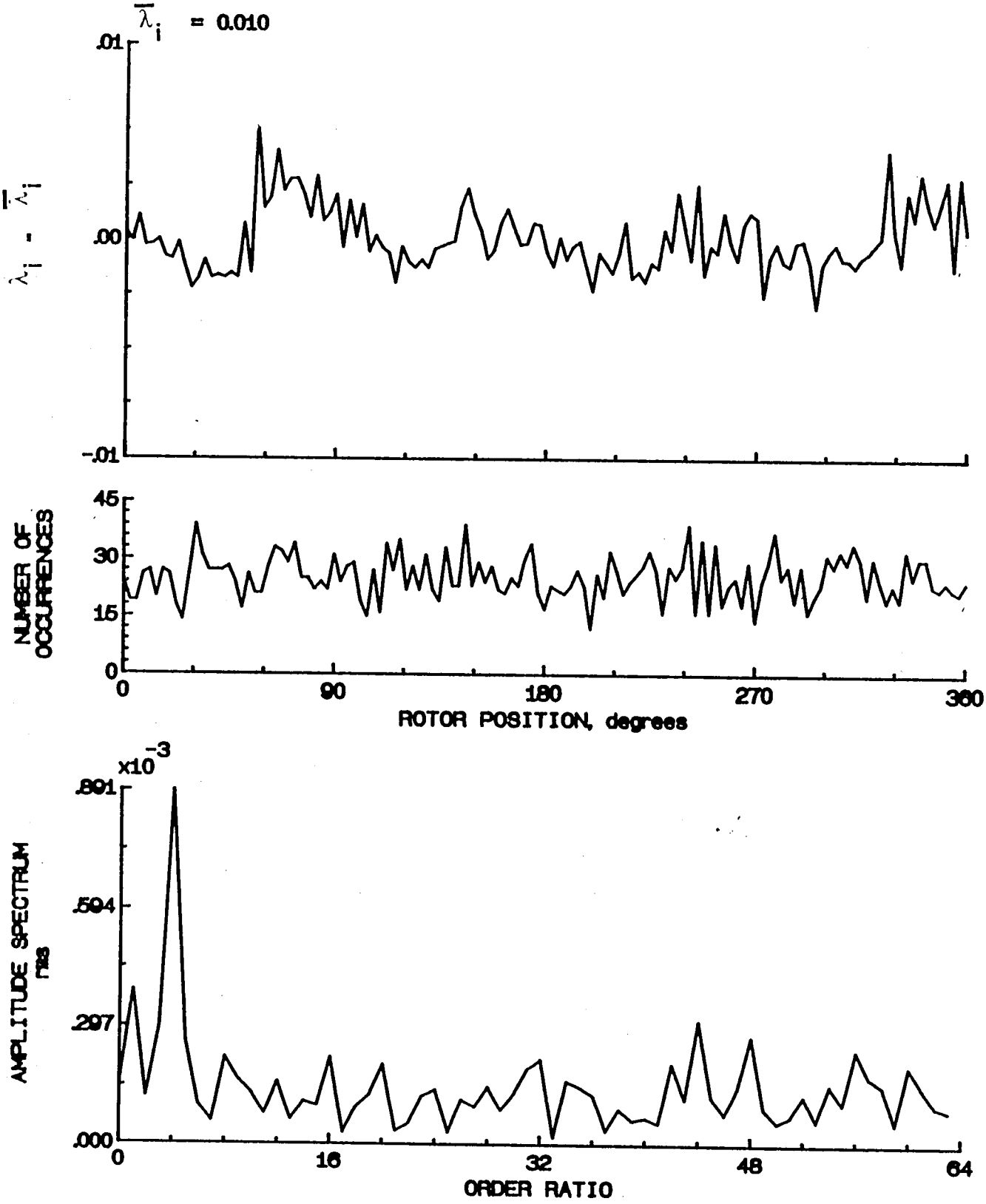


Figure 100.- Concluded.

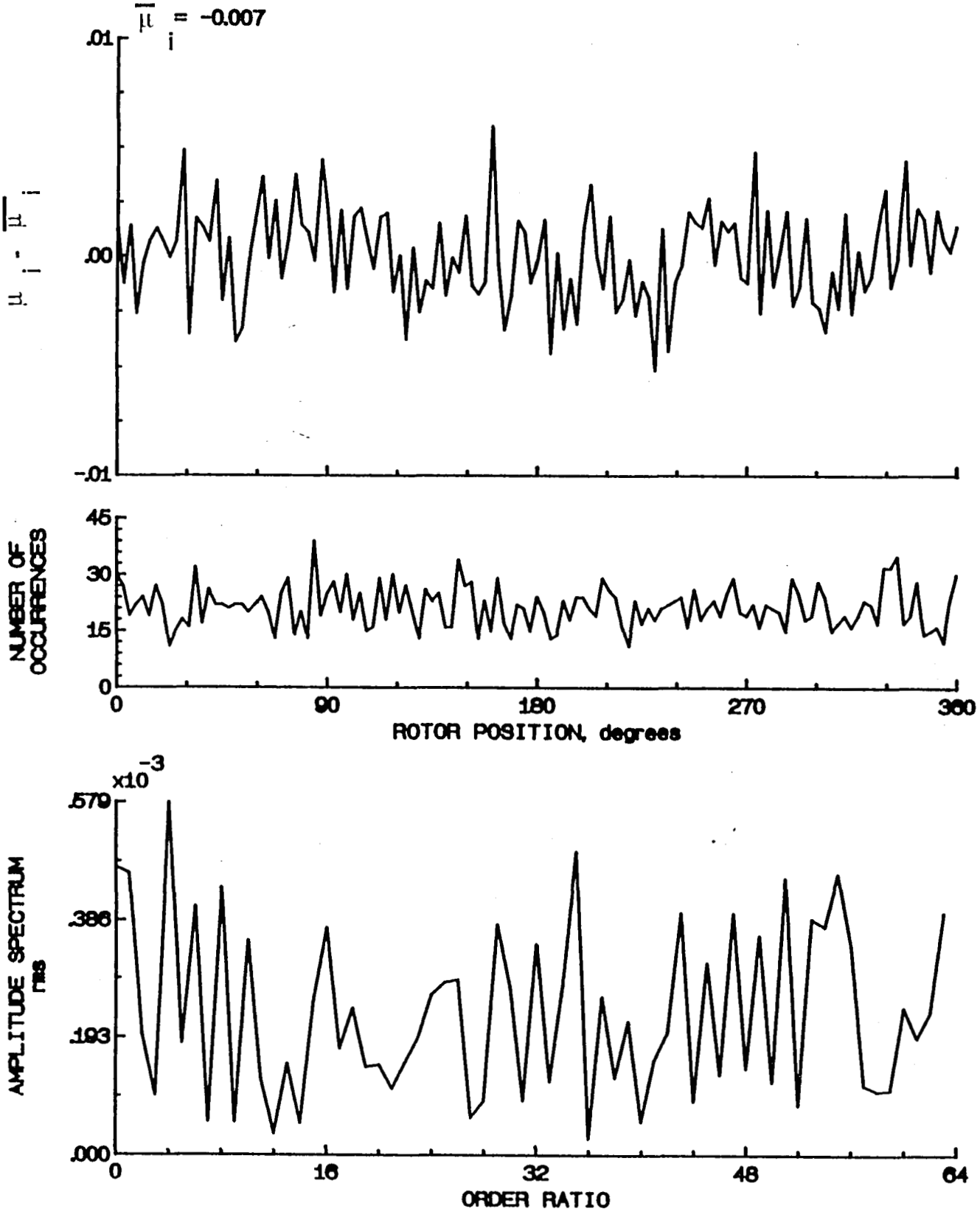


Figure 101.- Induced inflow velocity measured at 150 degrees and r/R of 1.04.

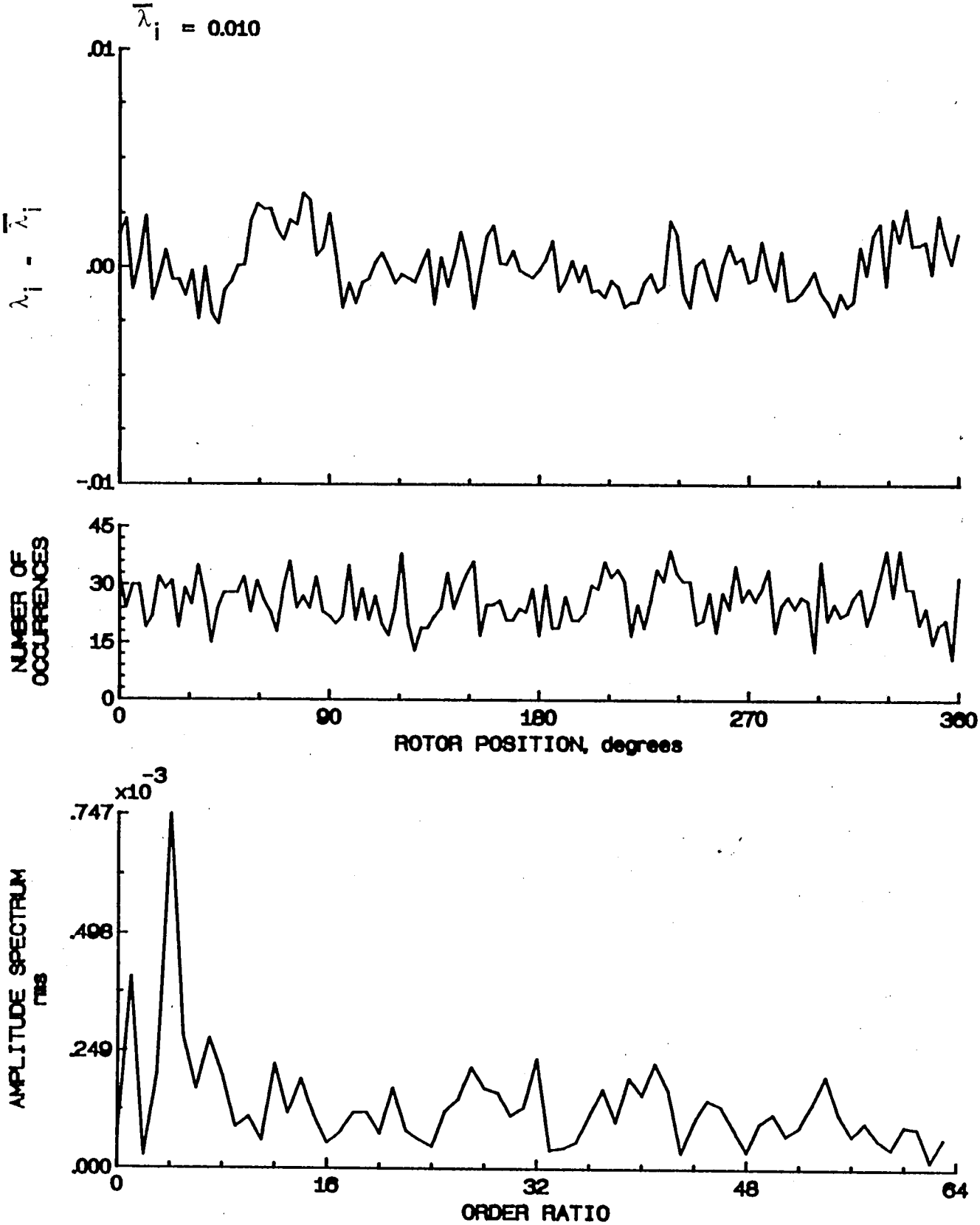


Figure 101.- Concluded.

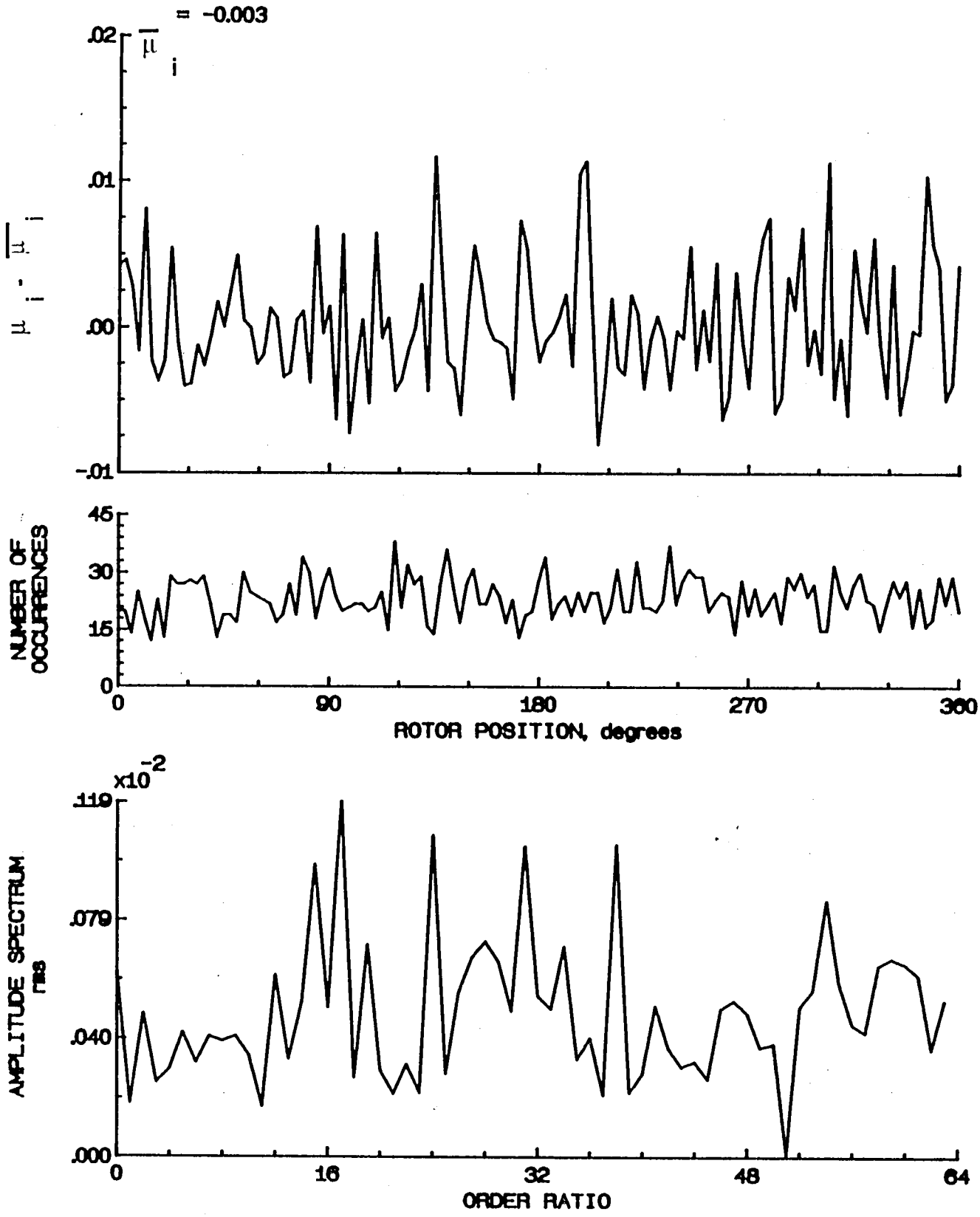


Figure 102.- Induced inflow velocity measured at 150 degrees and r/R of 1.10.

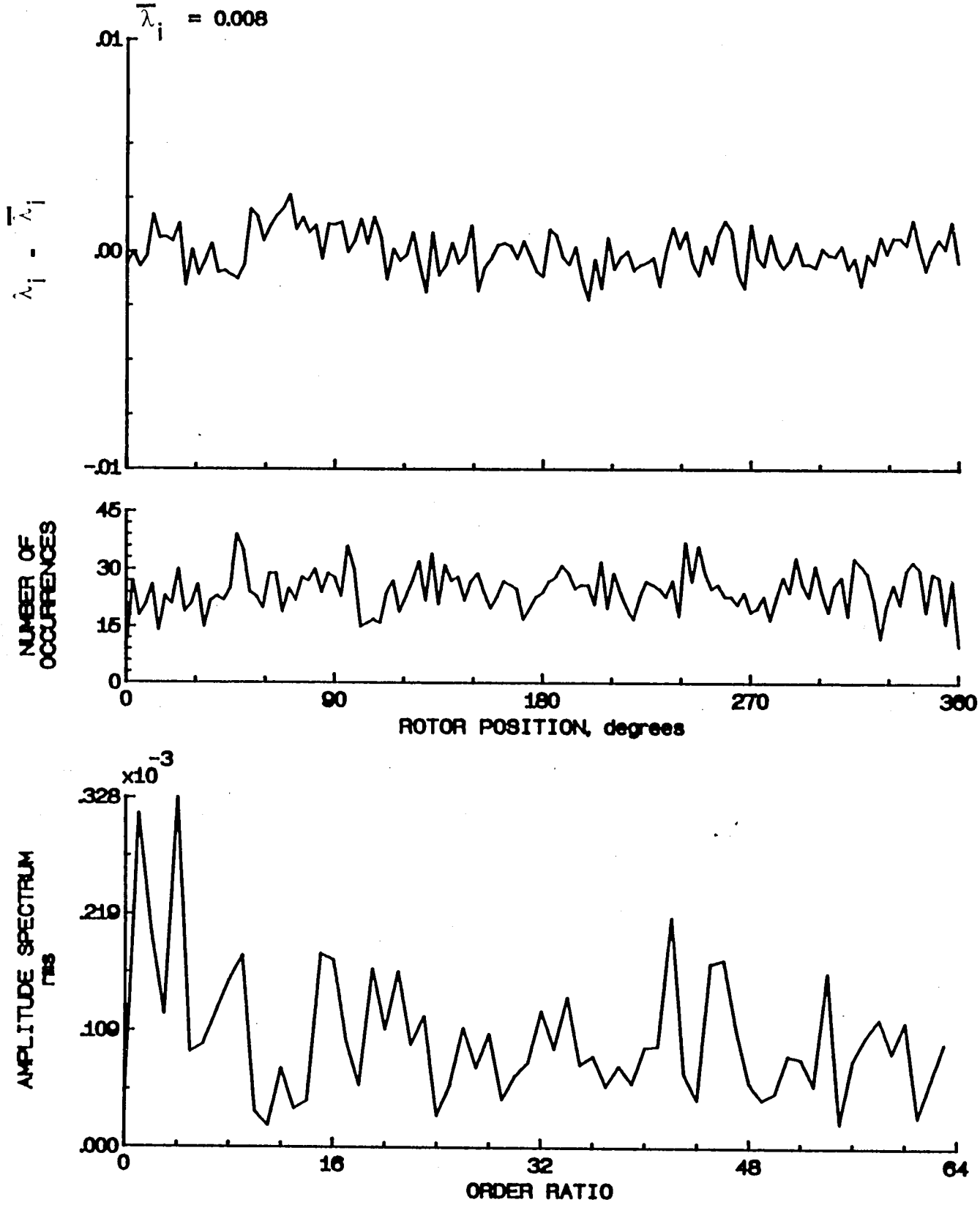


Figure 102.- Concluded.

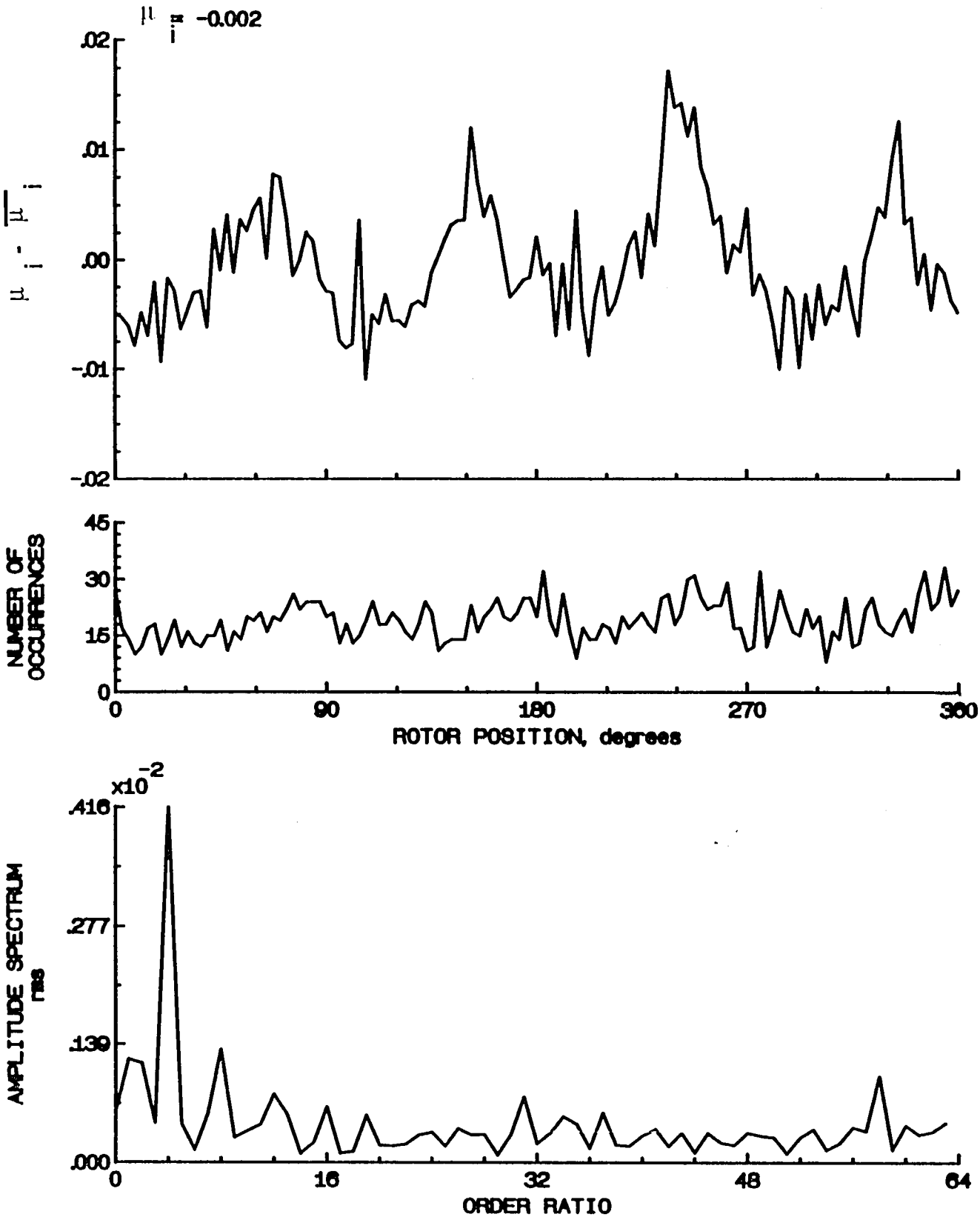


Figure 103.- Induced inflow velocity measured at 180 degrees and r/R of 0.20.

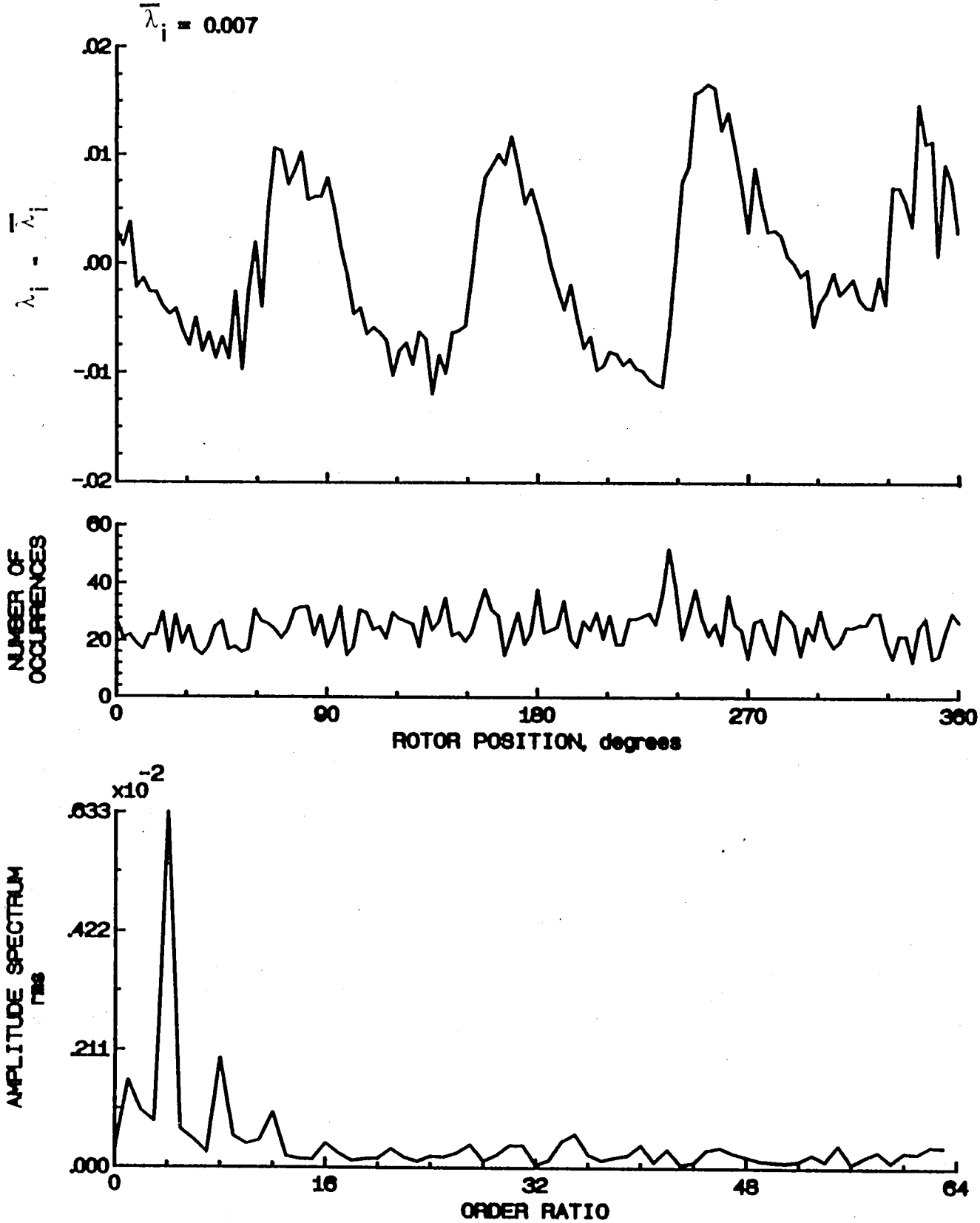


Figure 103.- Concluded.

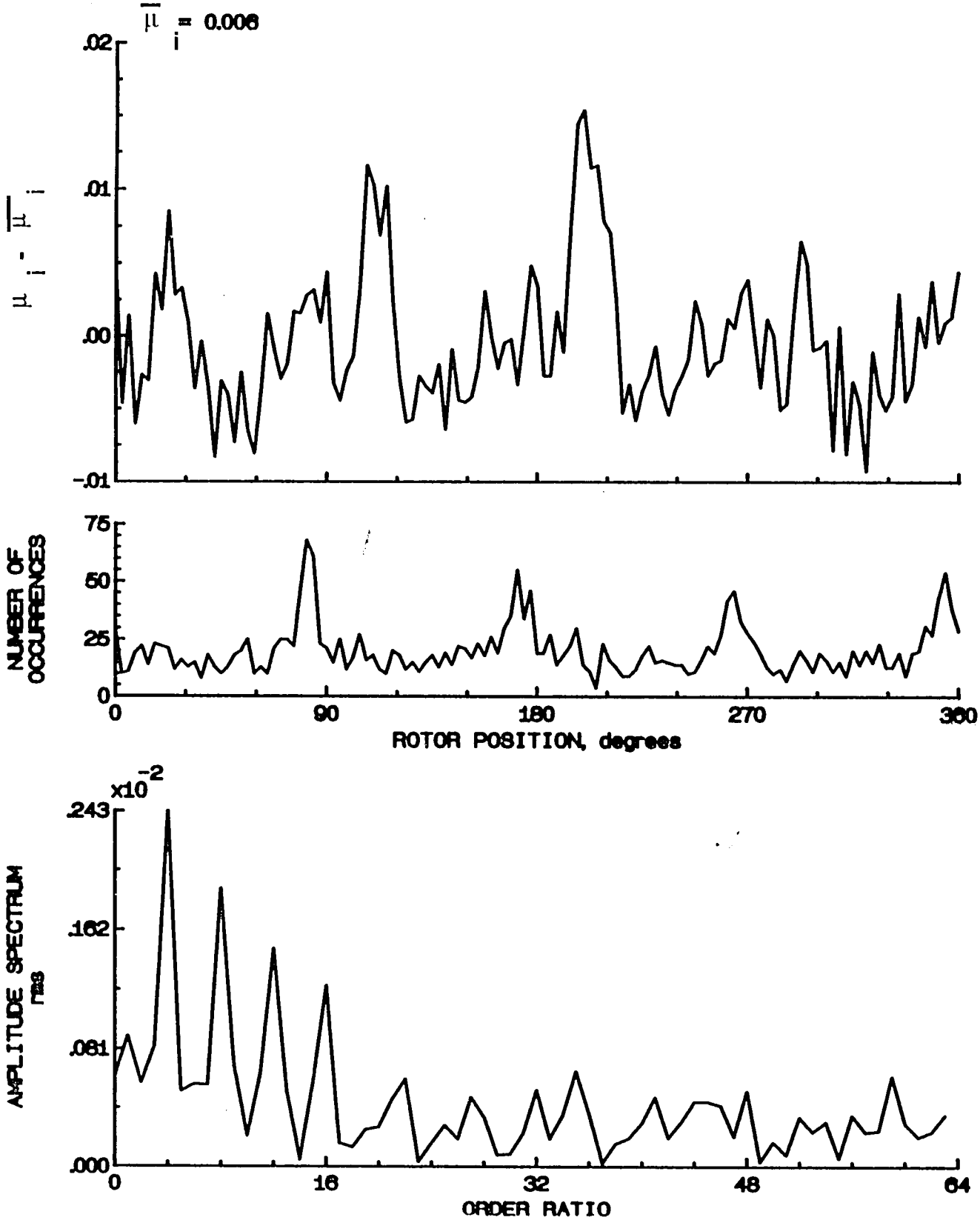


Figure 104.- Induced inflow velocity measured at 180 degrees and r/R of 0.40.

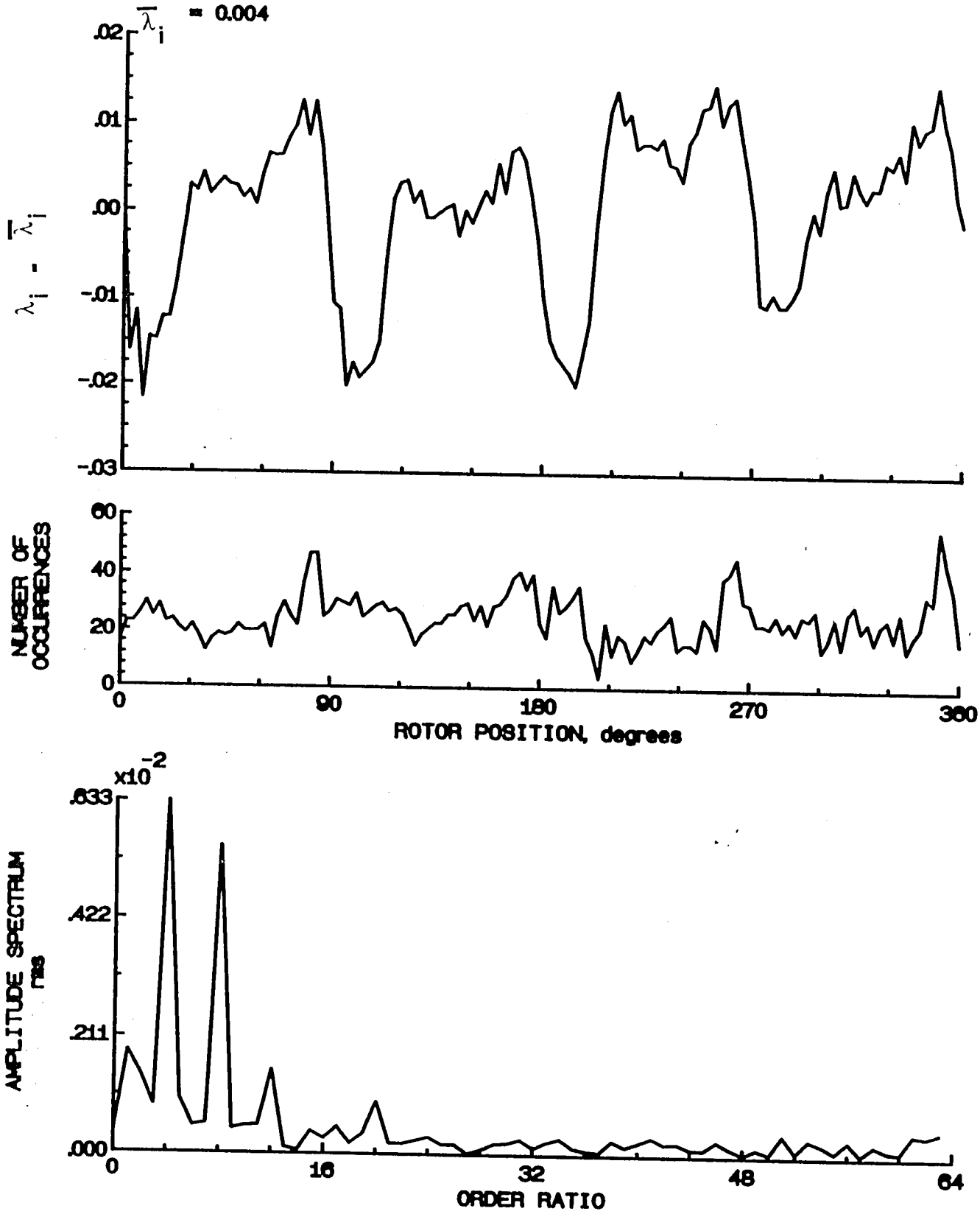


Figure 104.- Concluded.

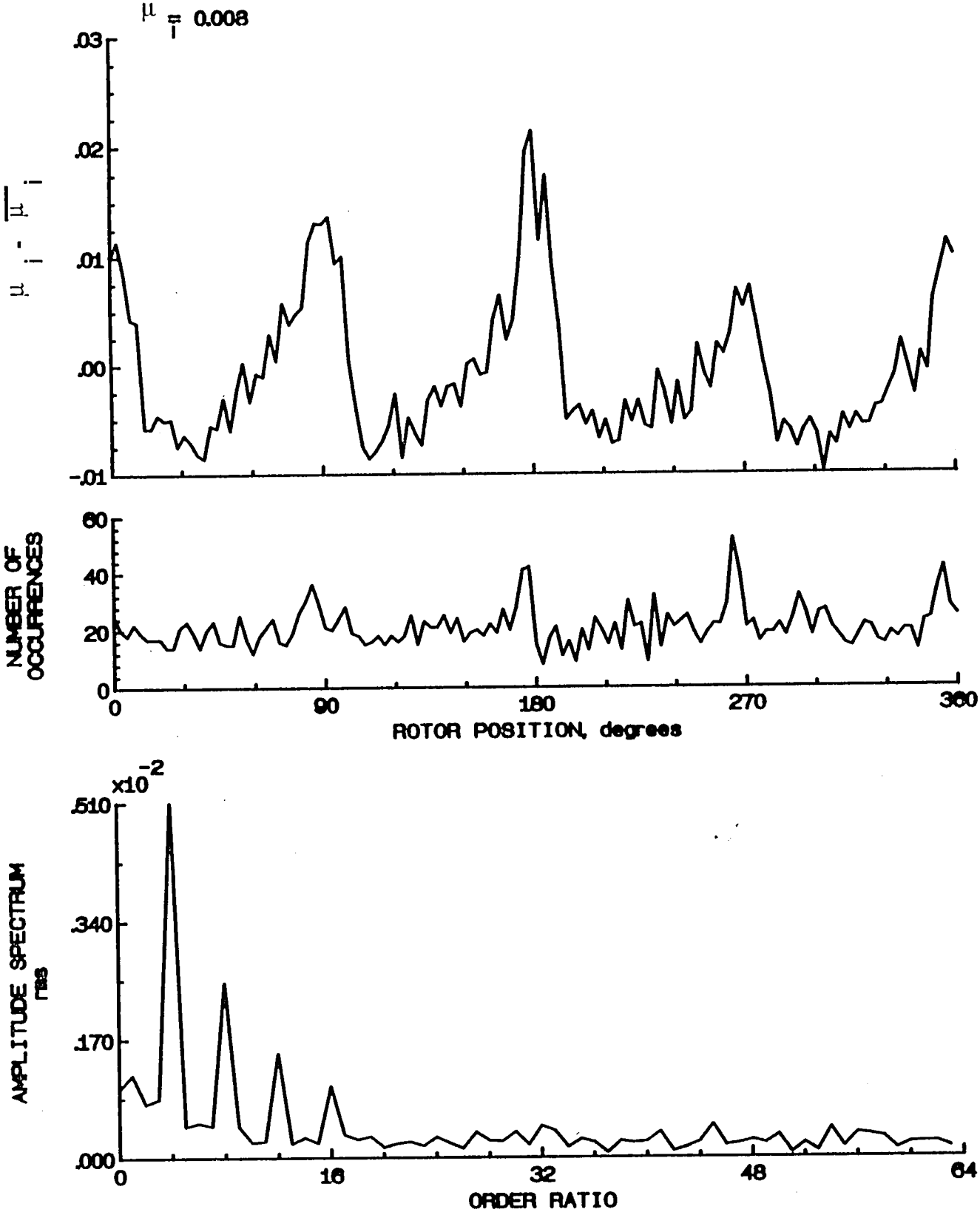
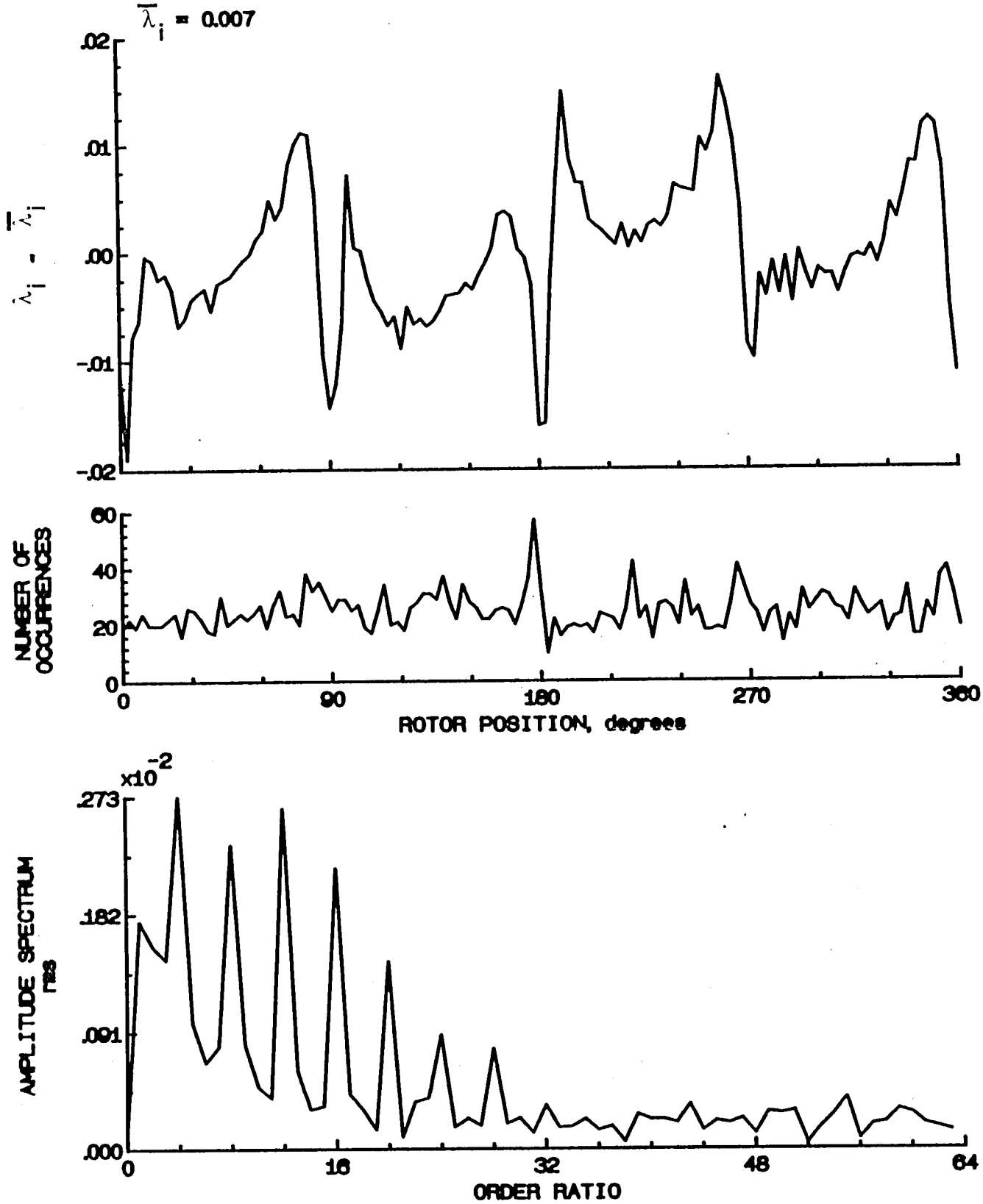


Figure 105.- Induced inflow velocity measured at 180 degrees and r/R of 0.50.



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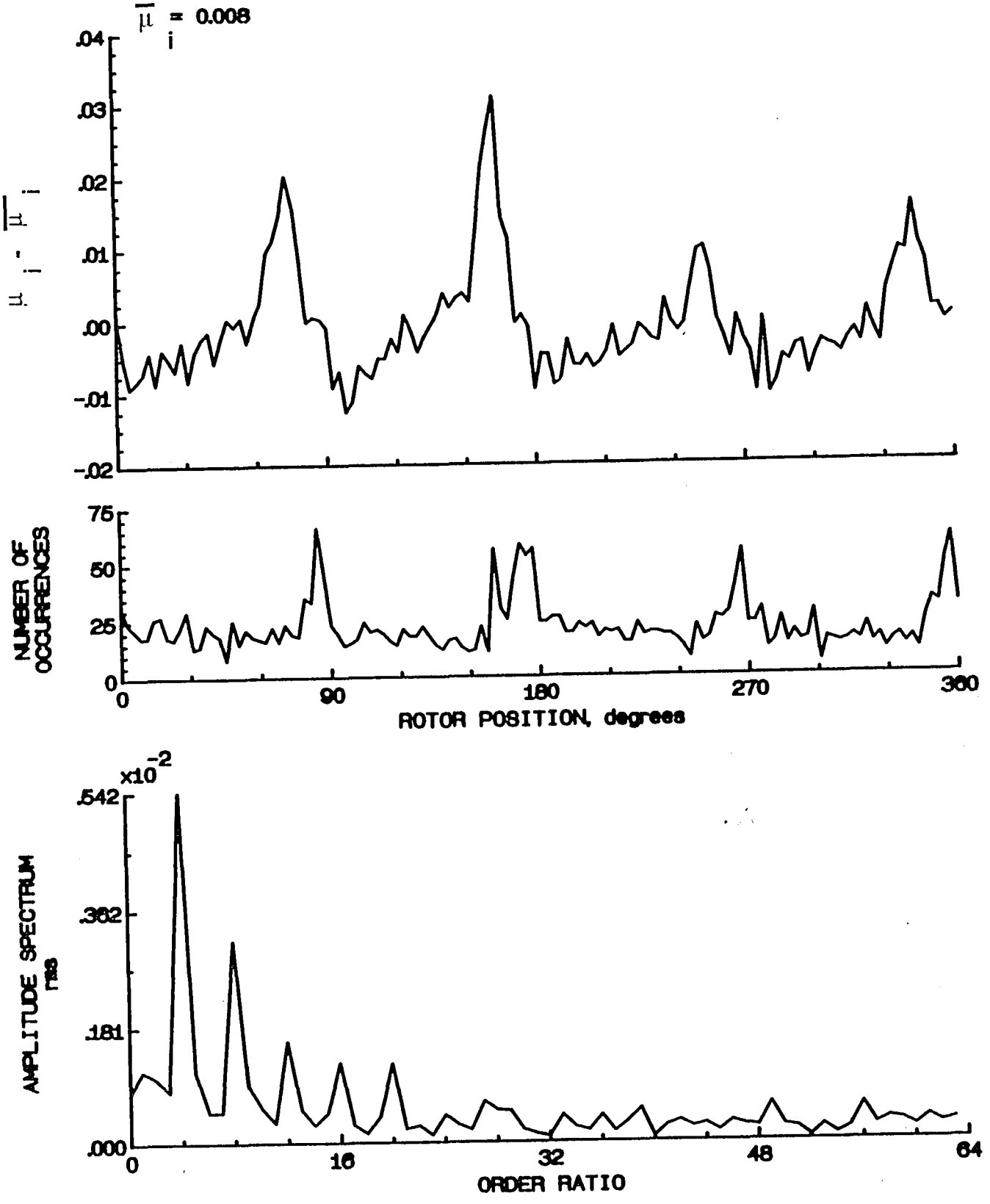


Figure 106.- Induced inflow velocity measured at 180 degrees and r/R of 0.60.

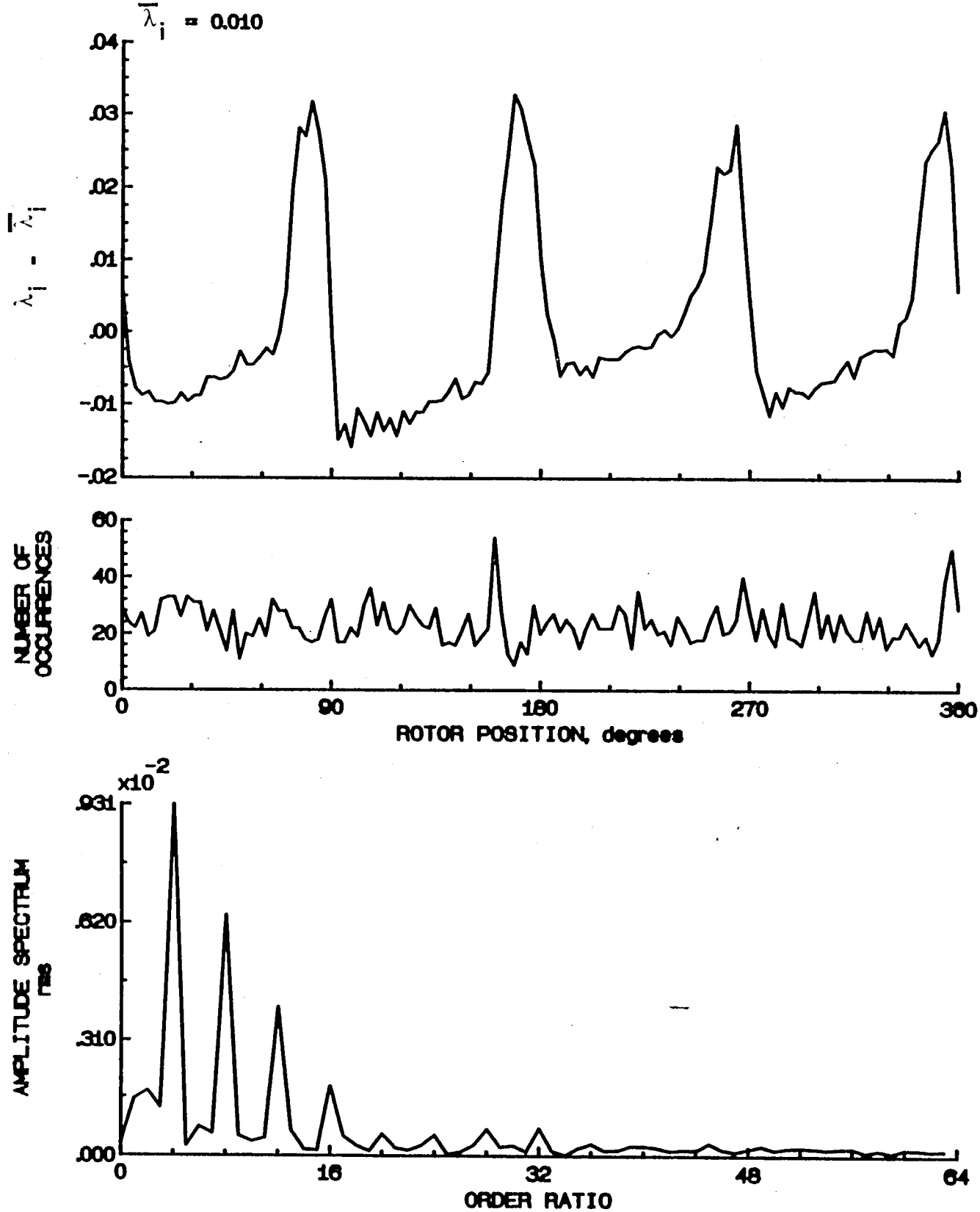


Figure 106.- Concluded.

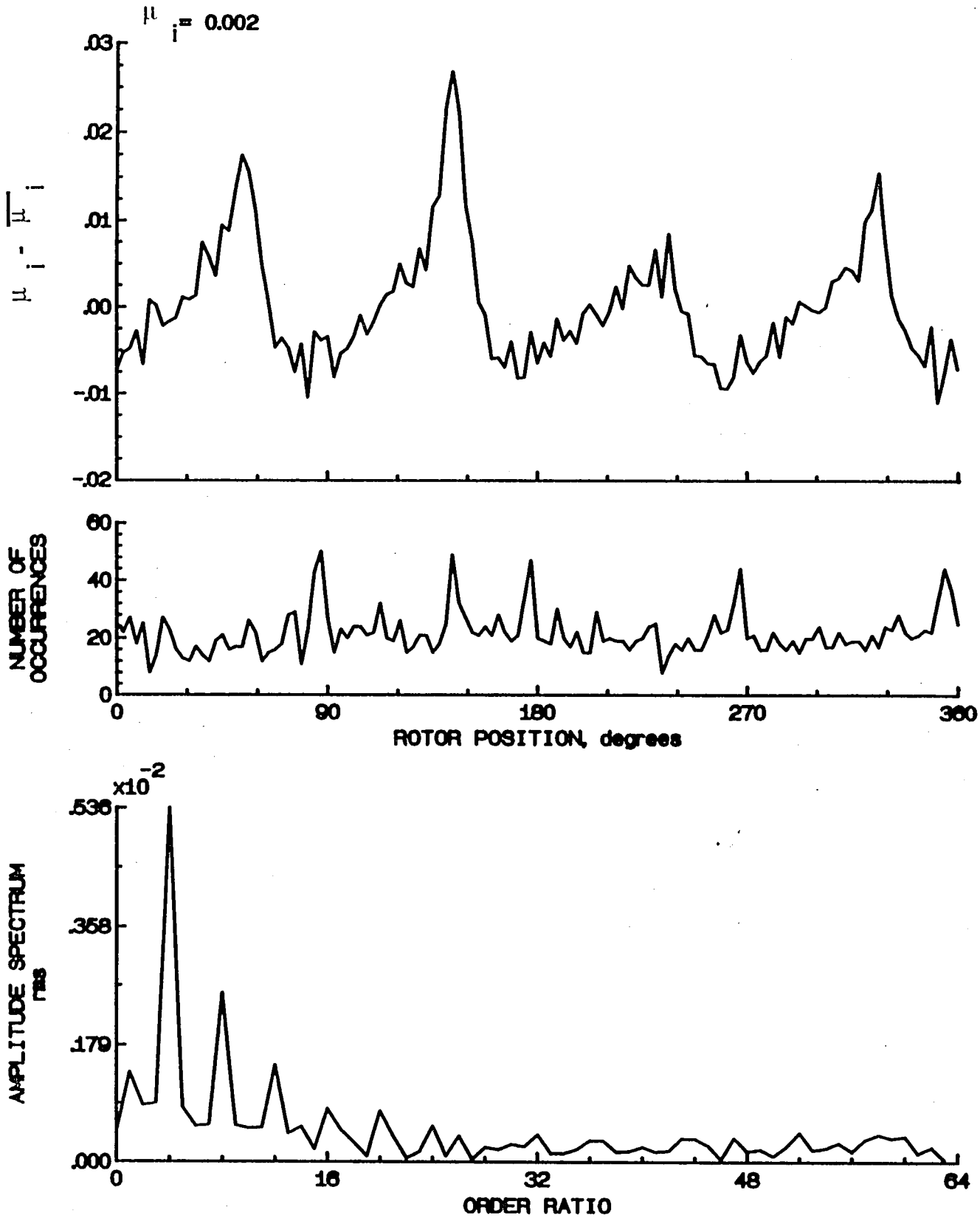


Figure 107.- Induced inflow velocity measured at 180 degrees and r/R of 0.70.

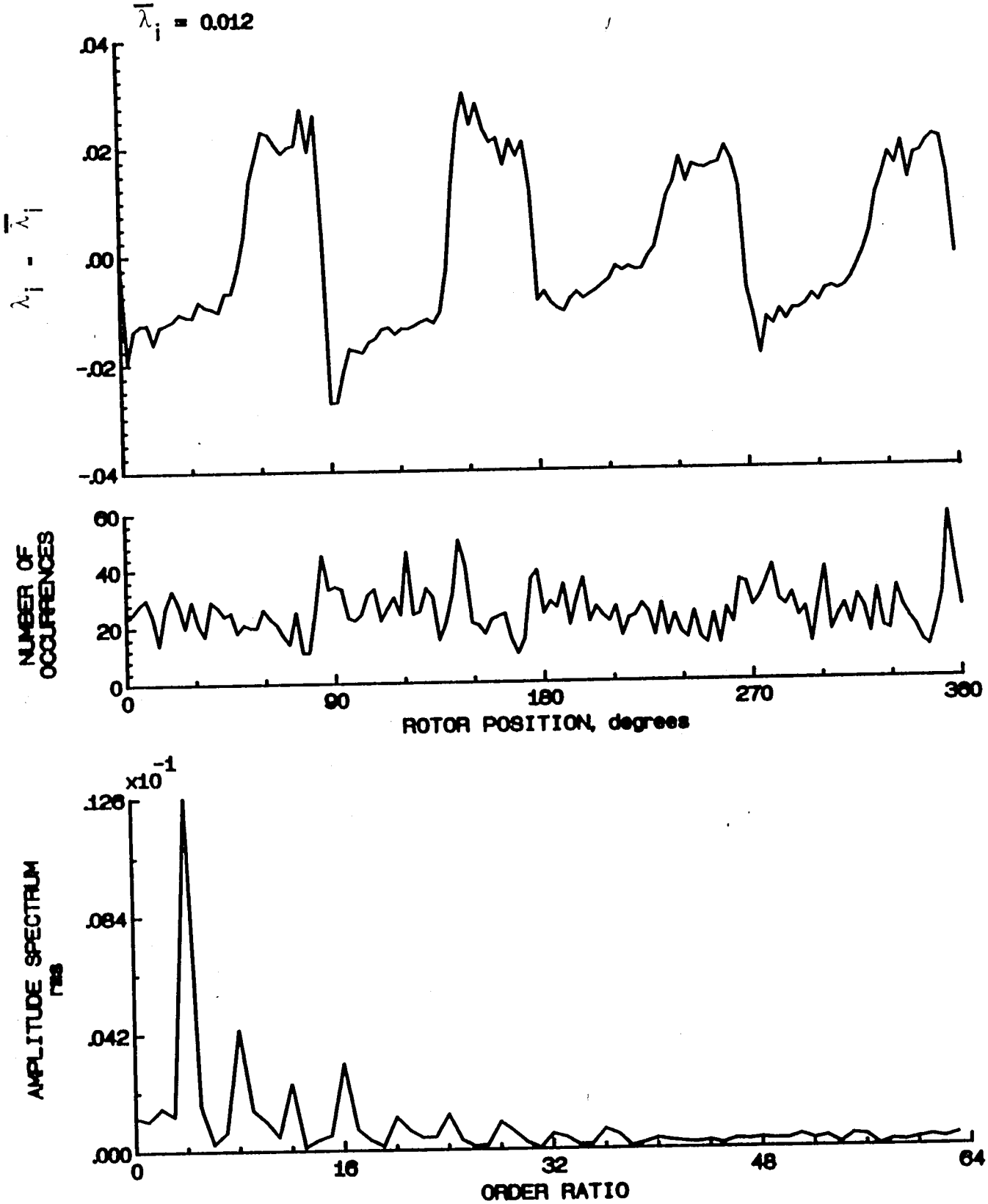


Figure 107.- Concluded.

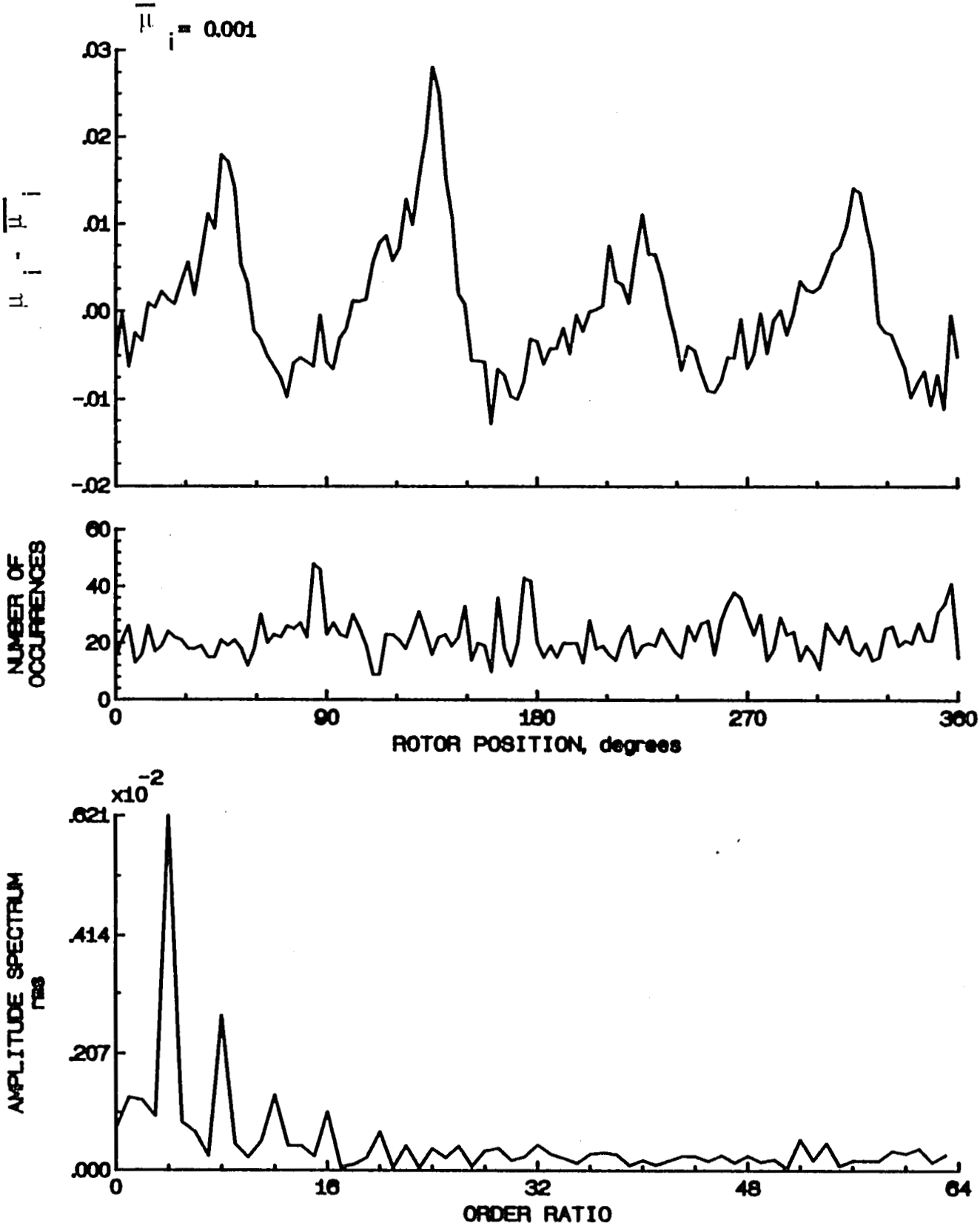


Figure 108.- Induced inflow velocity measured at 180 degrees and r/R of 0.74.

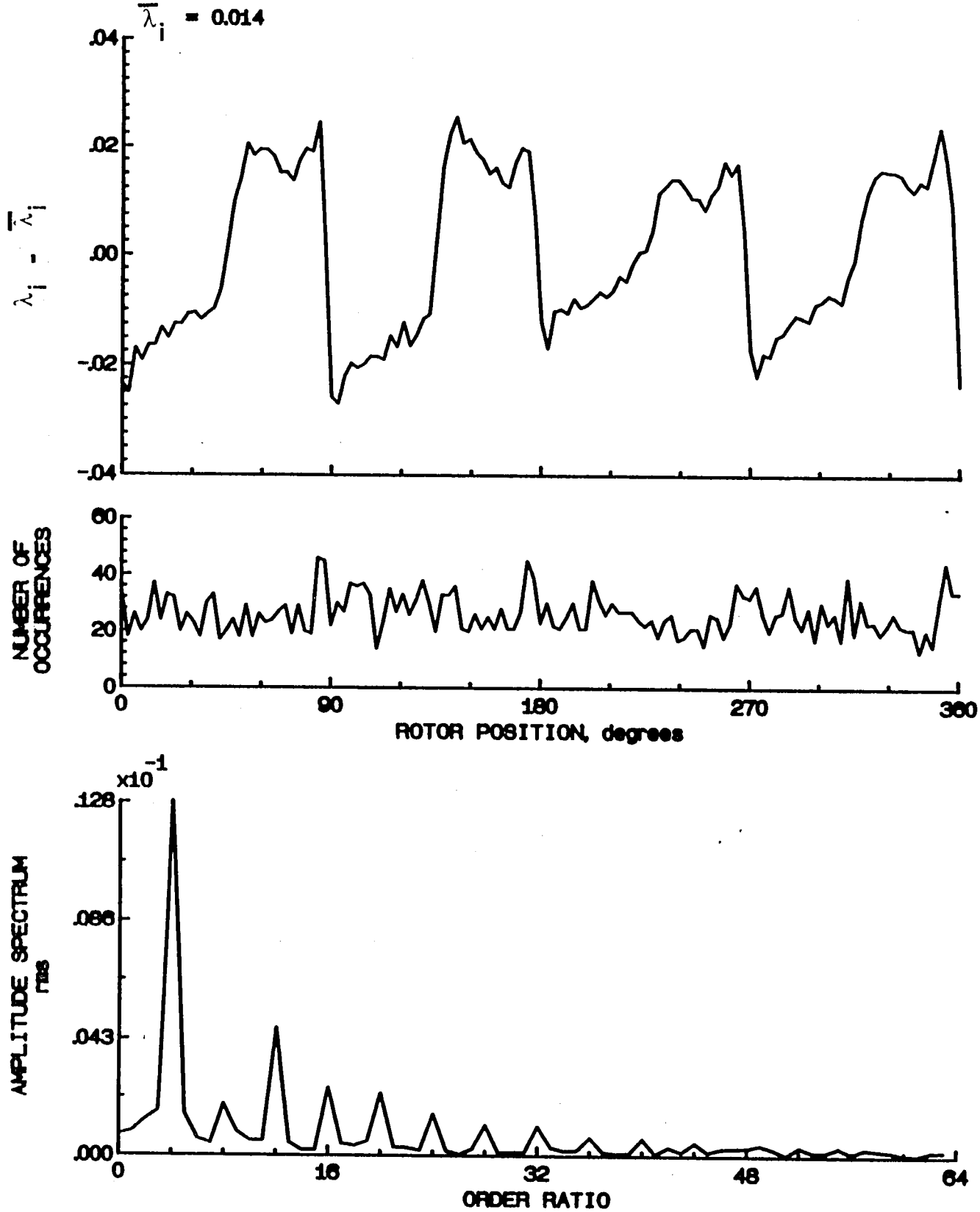


Figure 108.- Concluded.

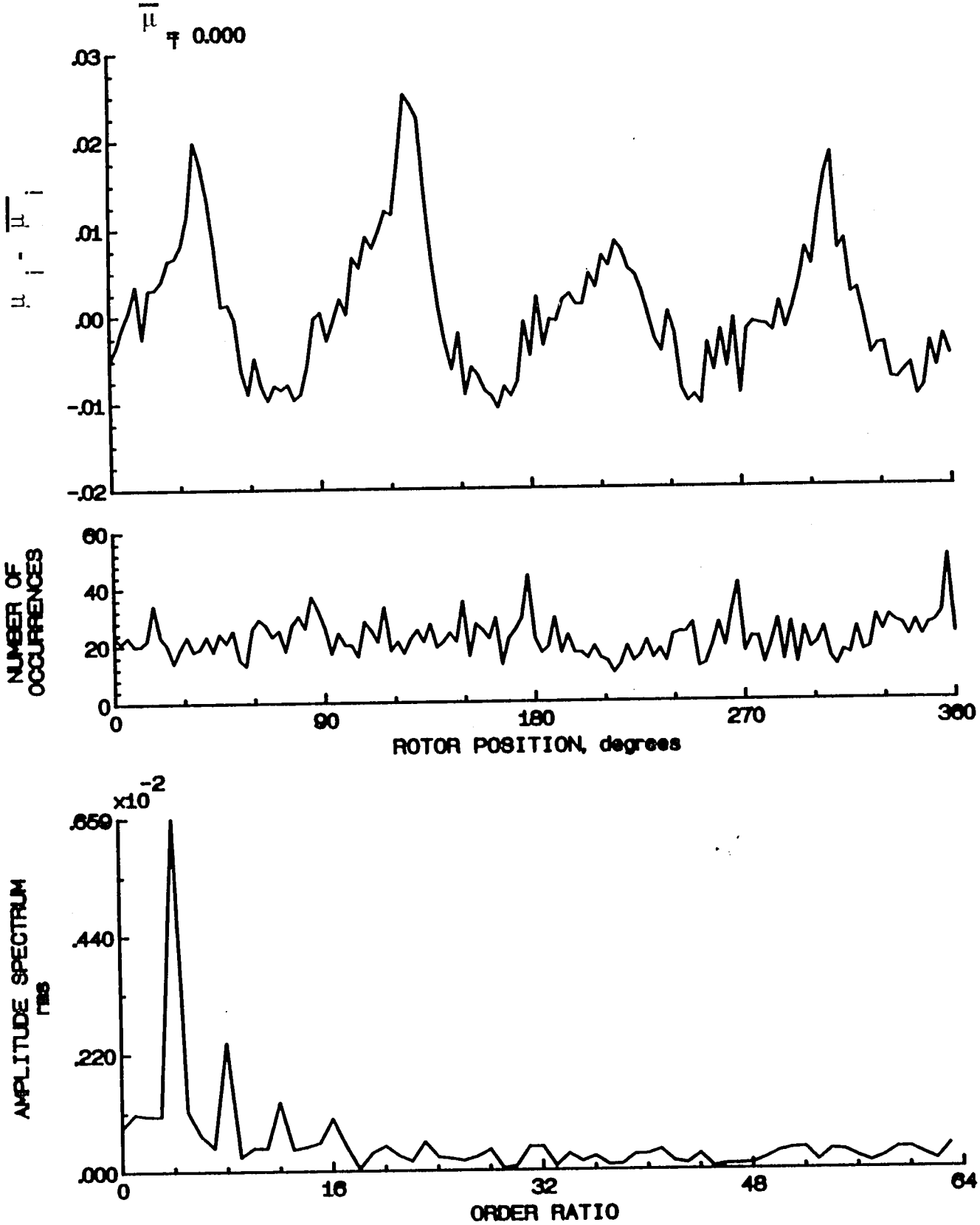


Figure 109.- Induced inflow velocity measured at 180 degrees and r/R of 0.78.

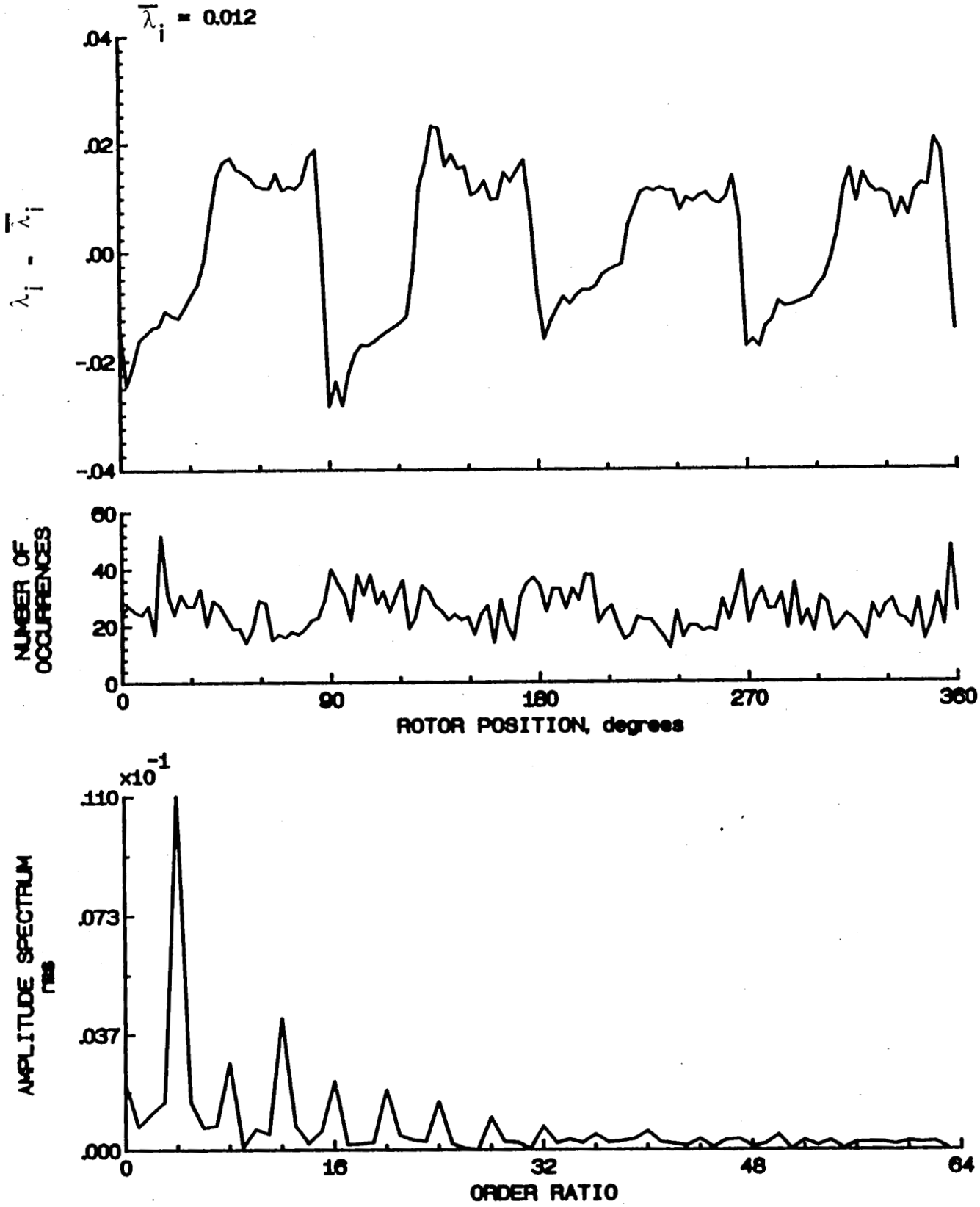


Figure 109.- Concluded.

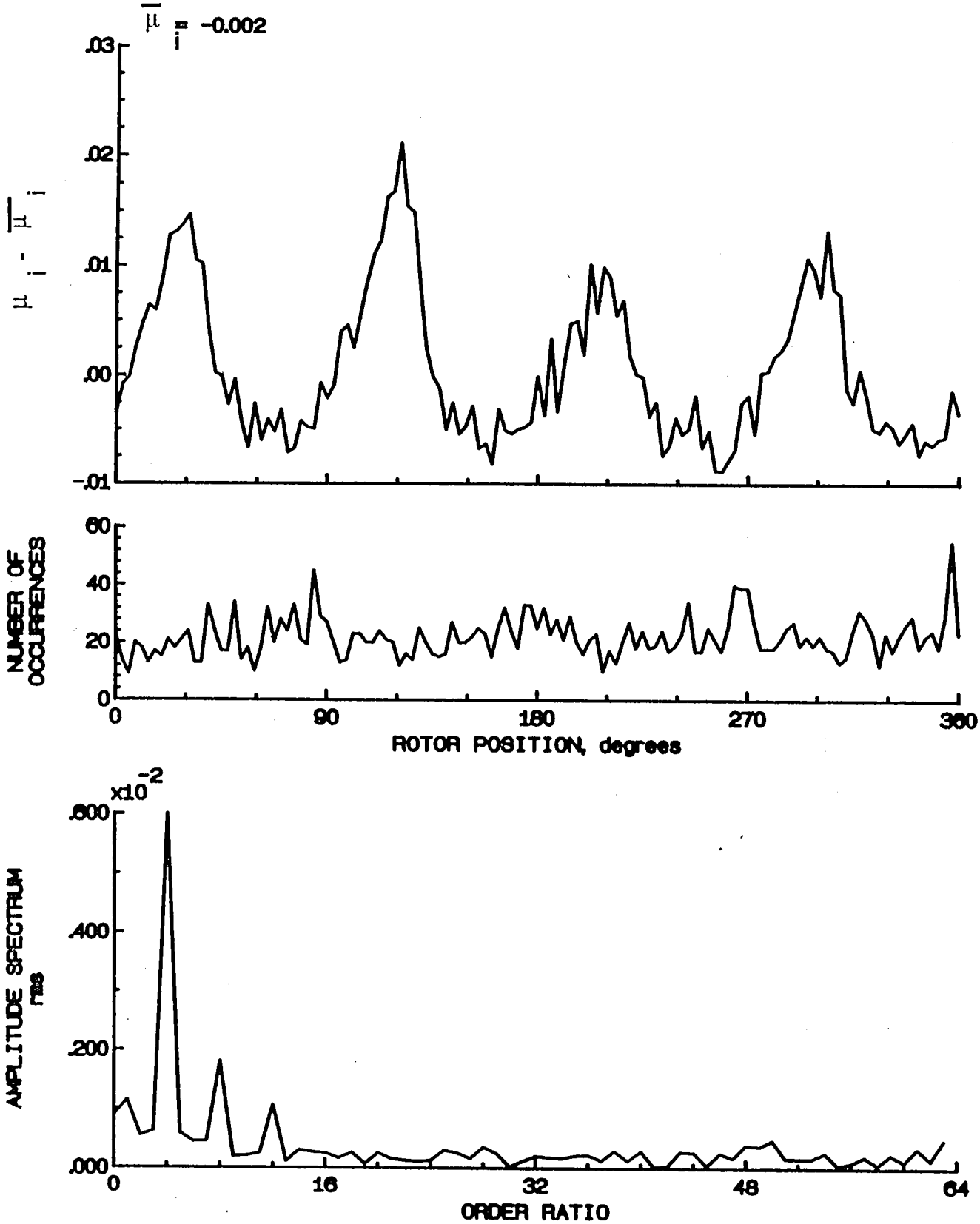
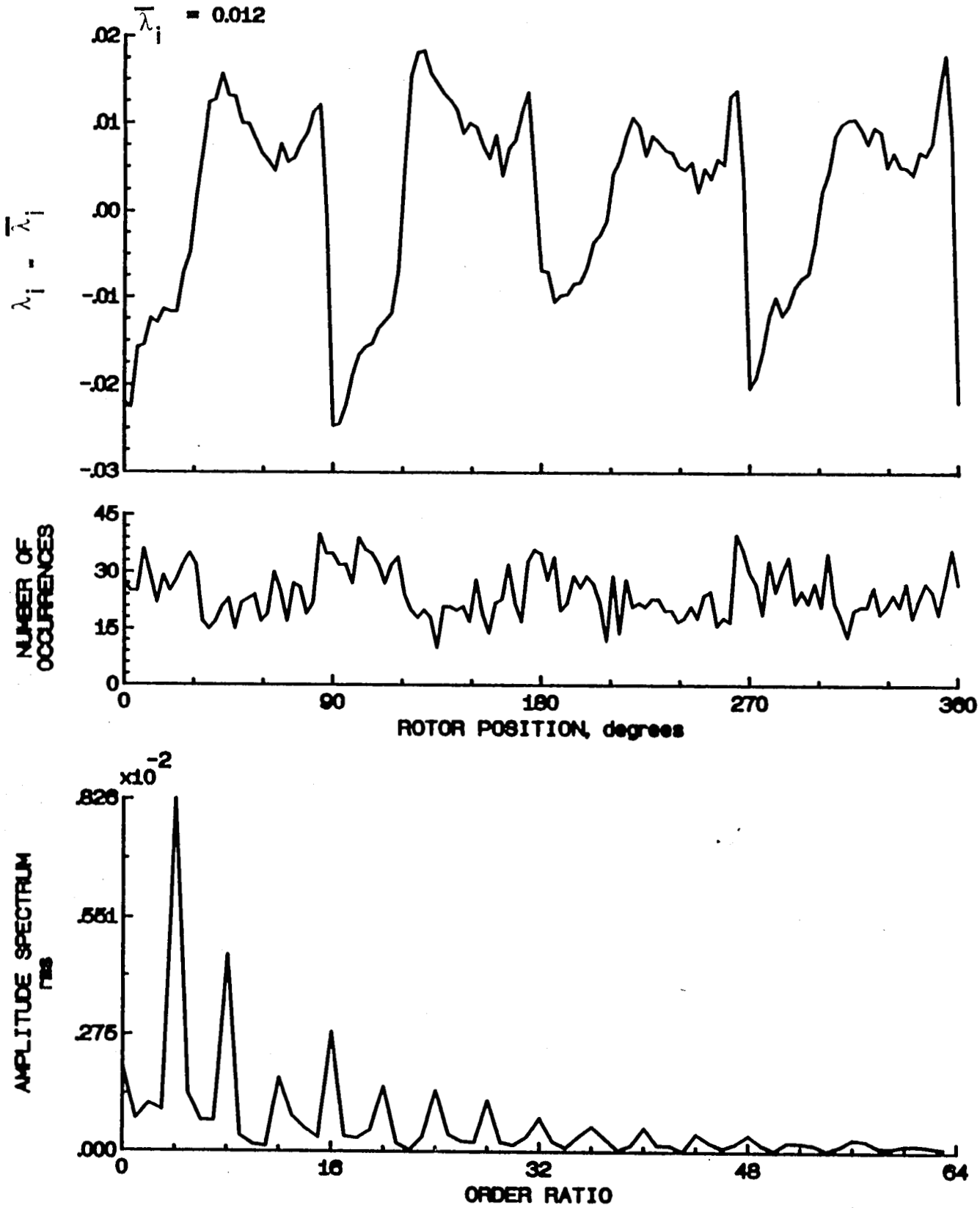


Figure 110.- Induced inflow velocity measured at 180 degrees and r/R of 0.82.



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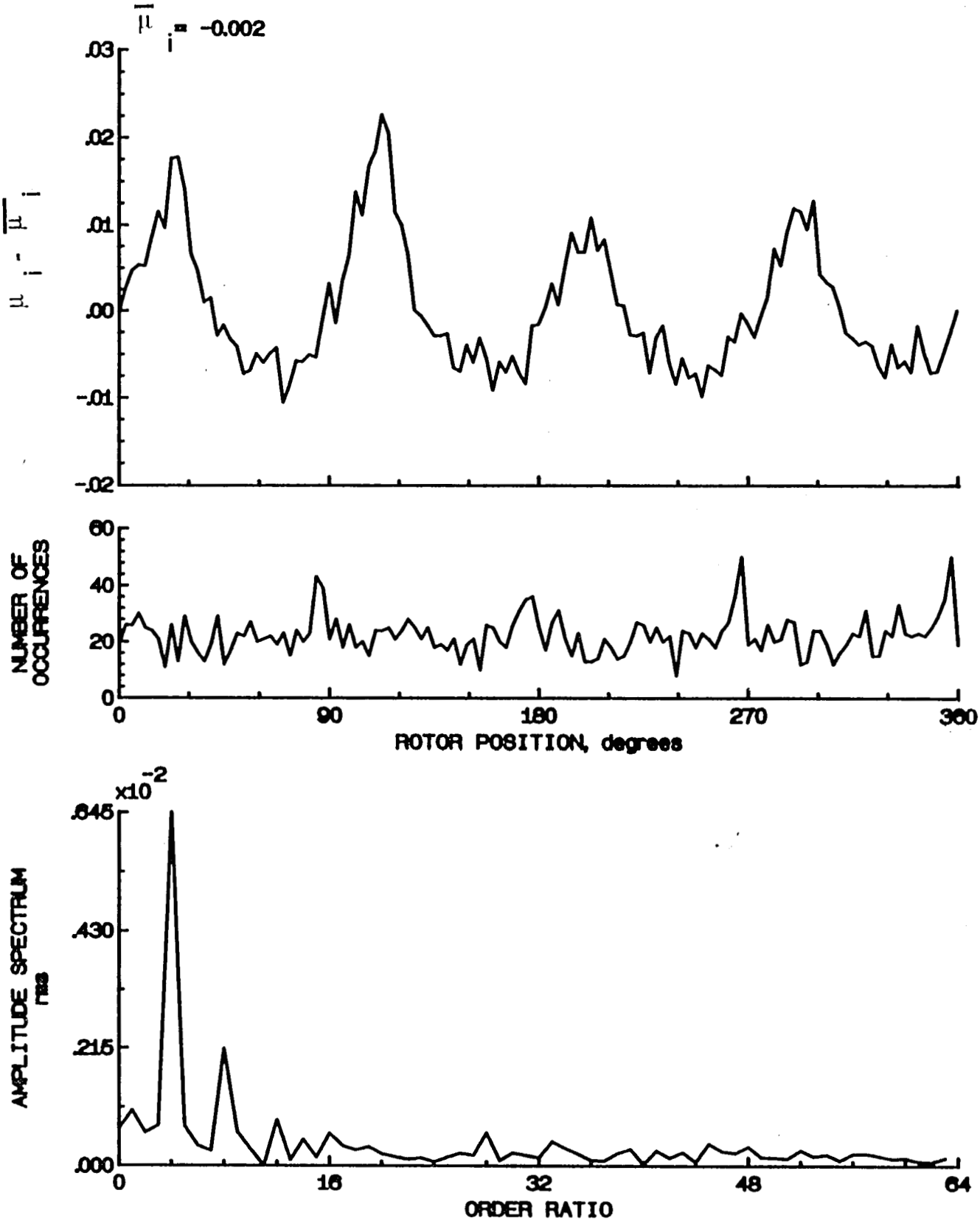
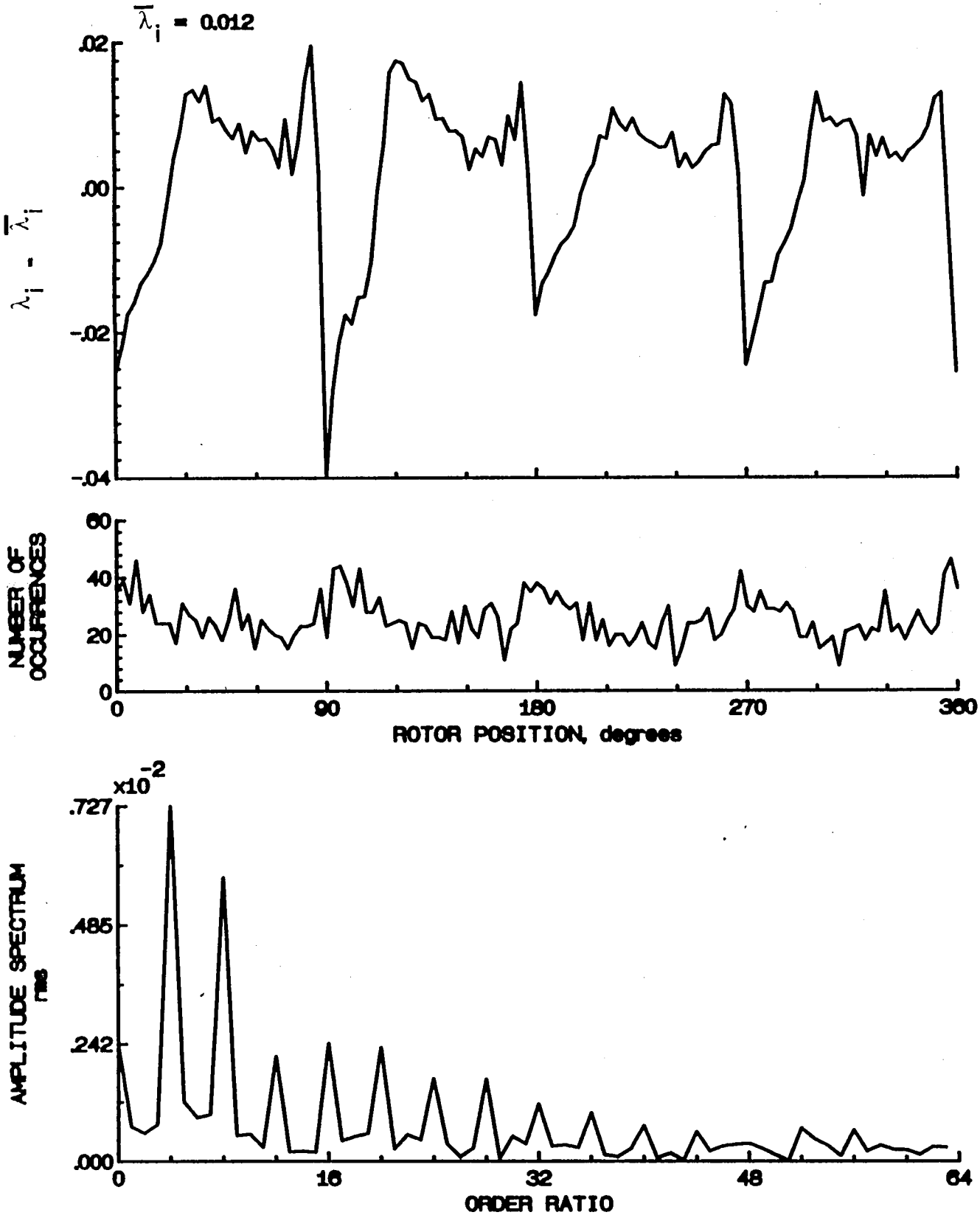


Figure 111.- Induced inflow velocity measured at 180 degrees and r/R of 0.86.



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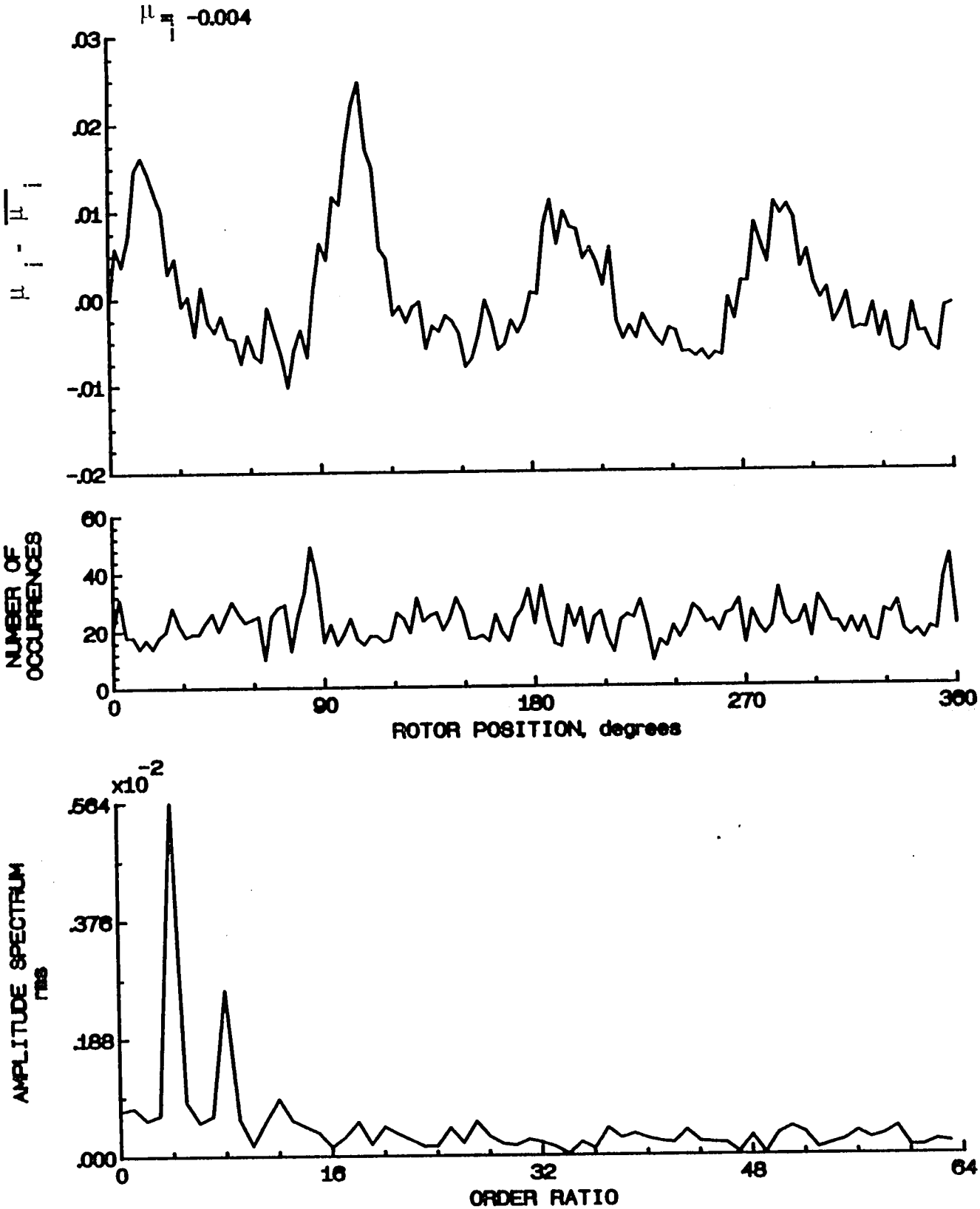
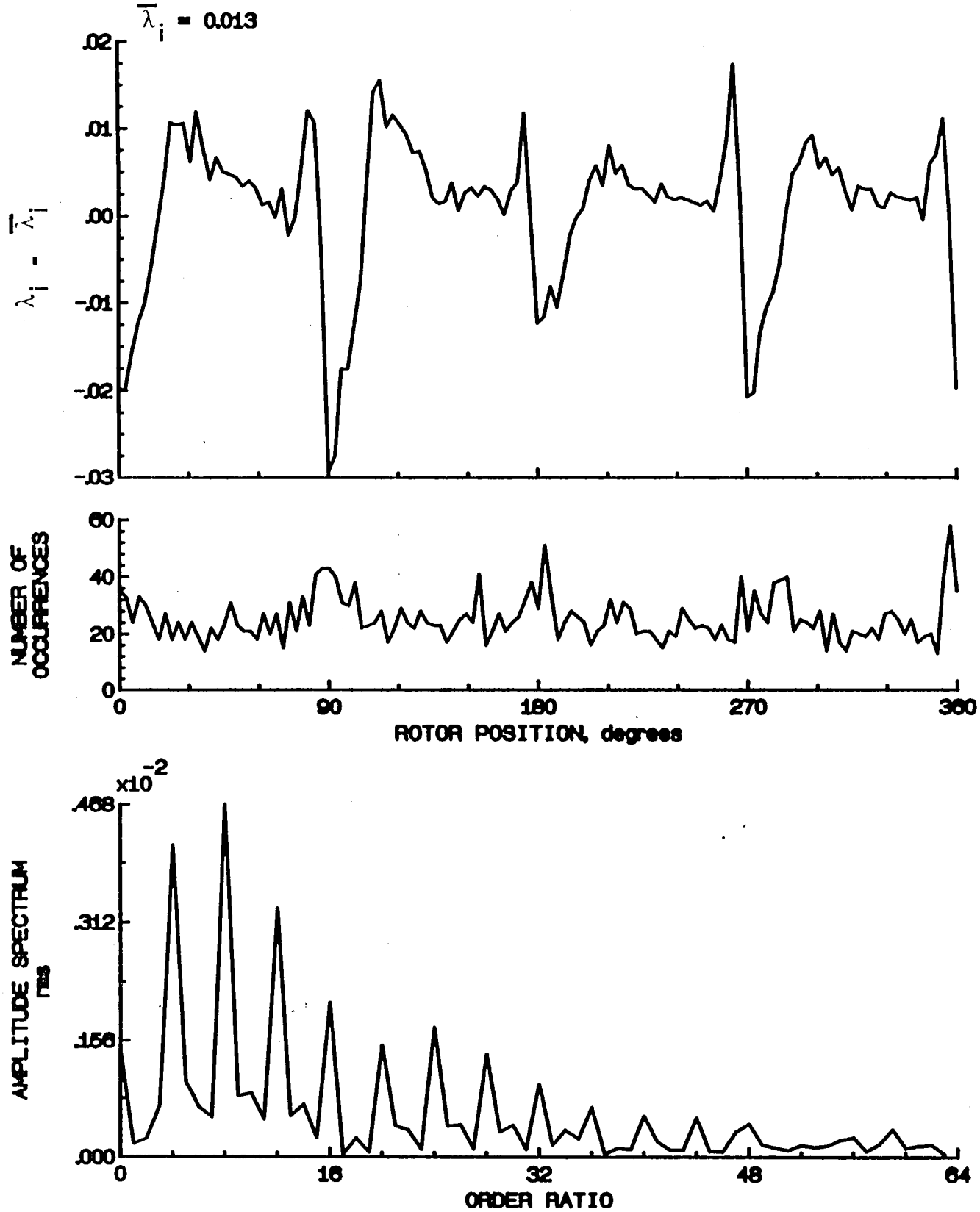


Figure 112.- Induced inflow velocity measured at 180 degrees and r/R of 0.90.



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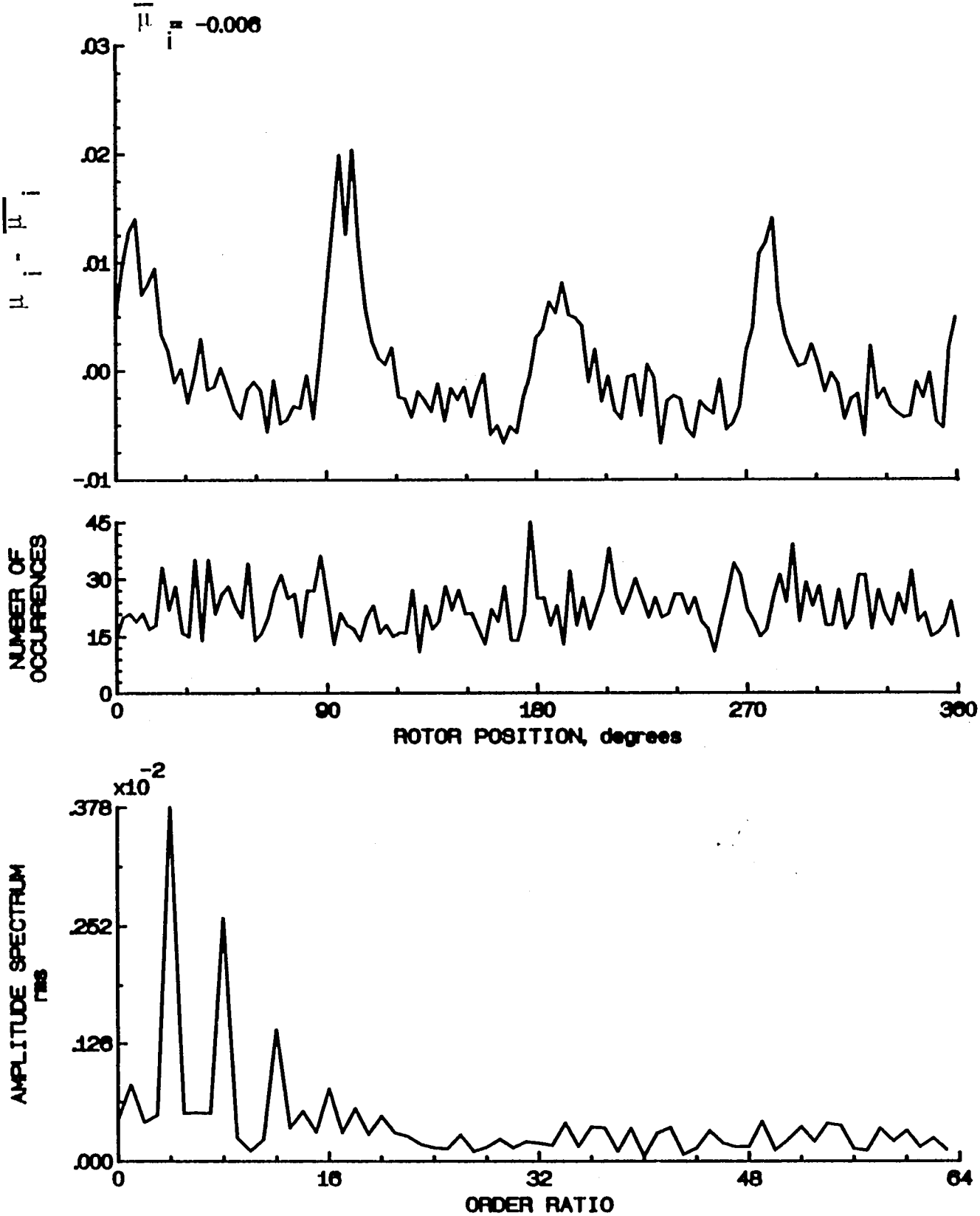
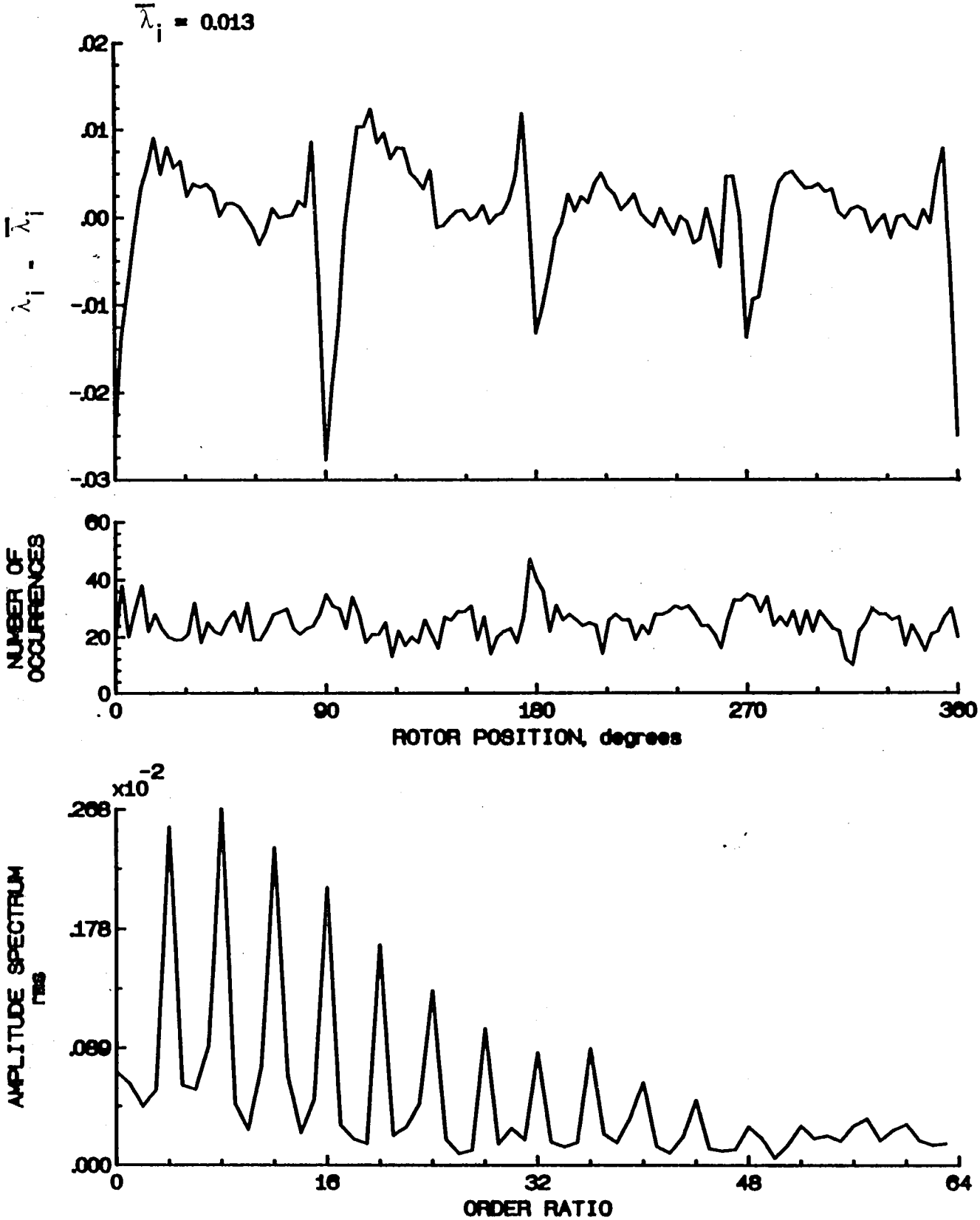


Figure 113.- Induced inflow velocity measured at 180 degrees and r/R of 0.94.



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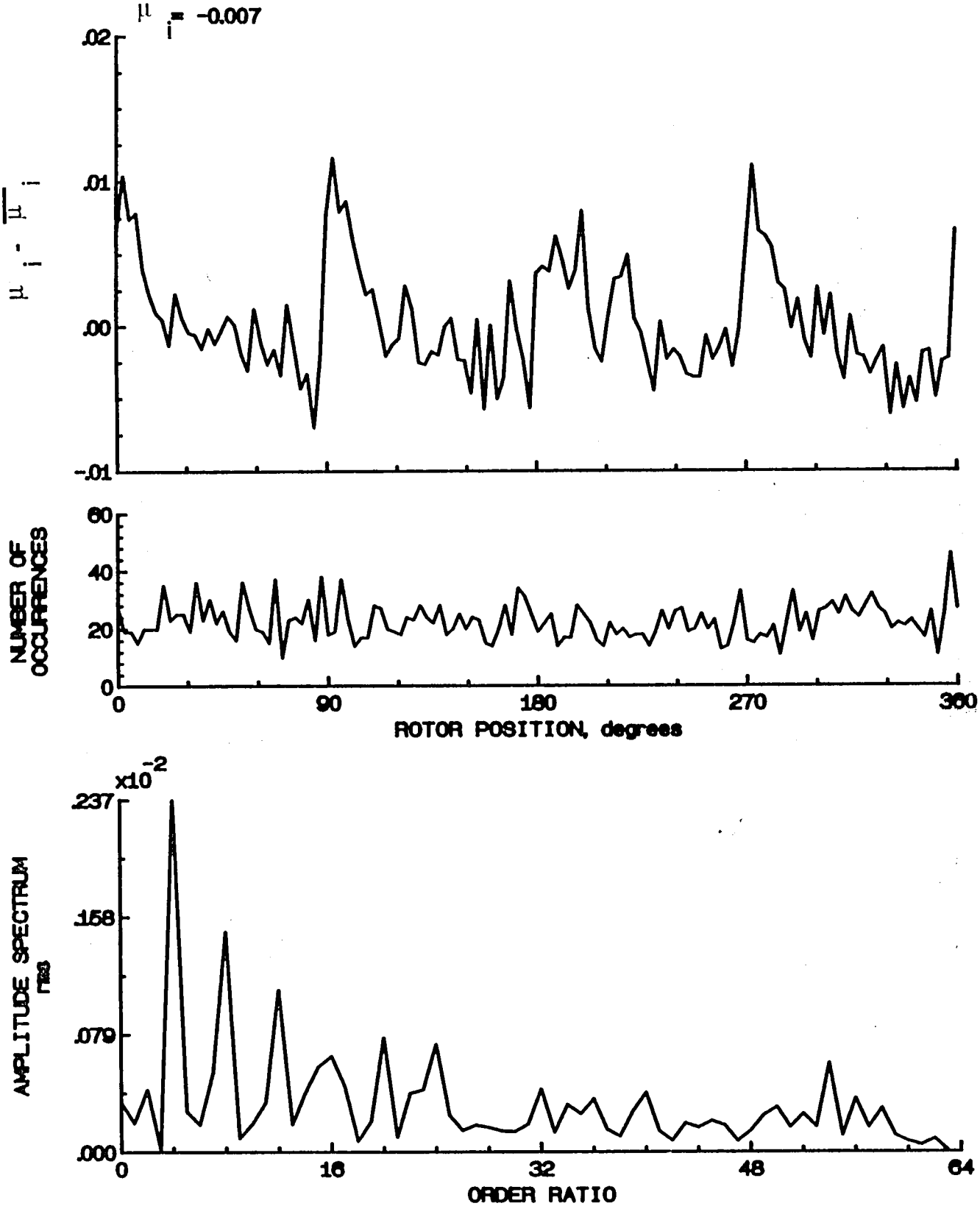


Figure 114.- Induced inflow velocity measured at 180 degrees and r/R of 0.98.

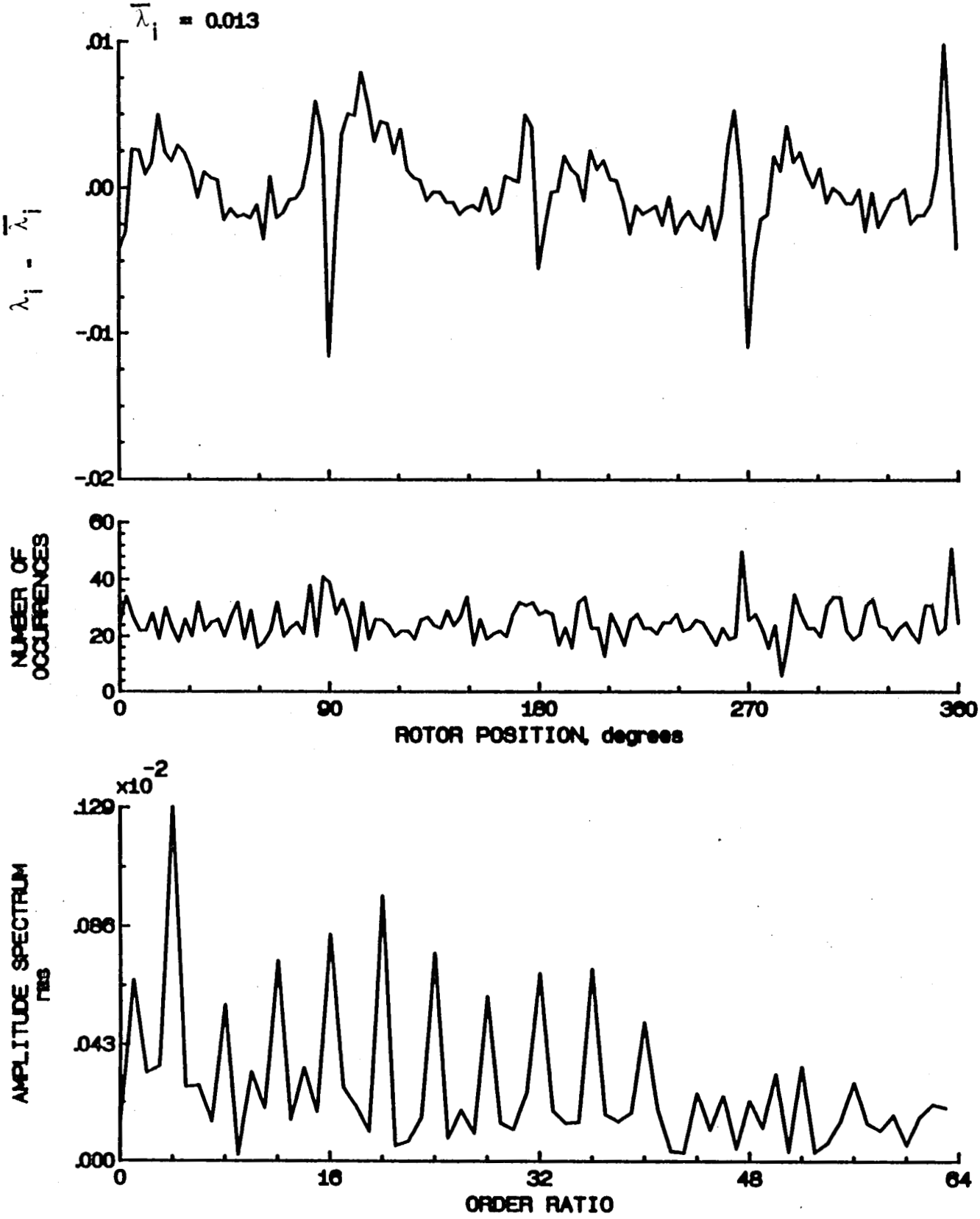


Figure 114.- Concluded.

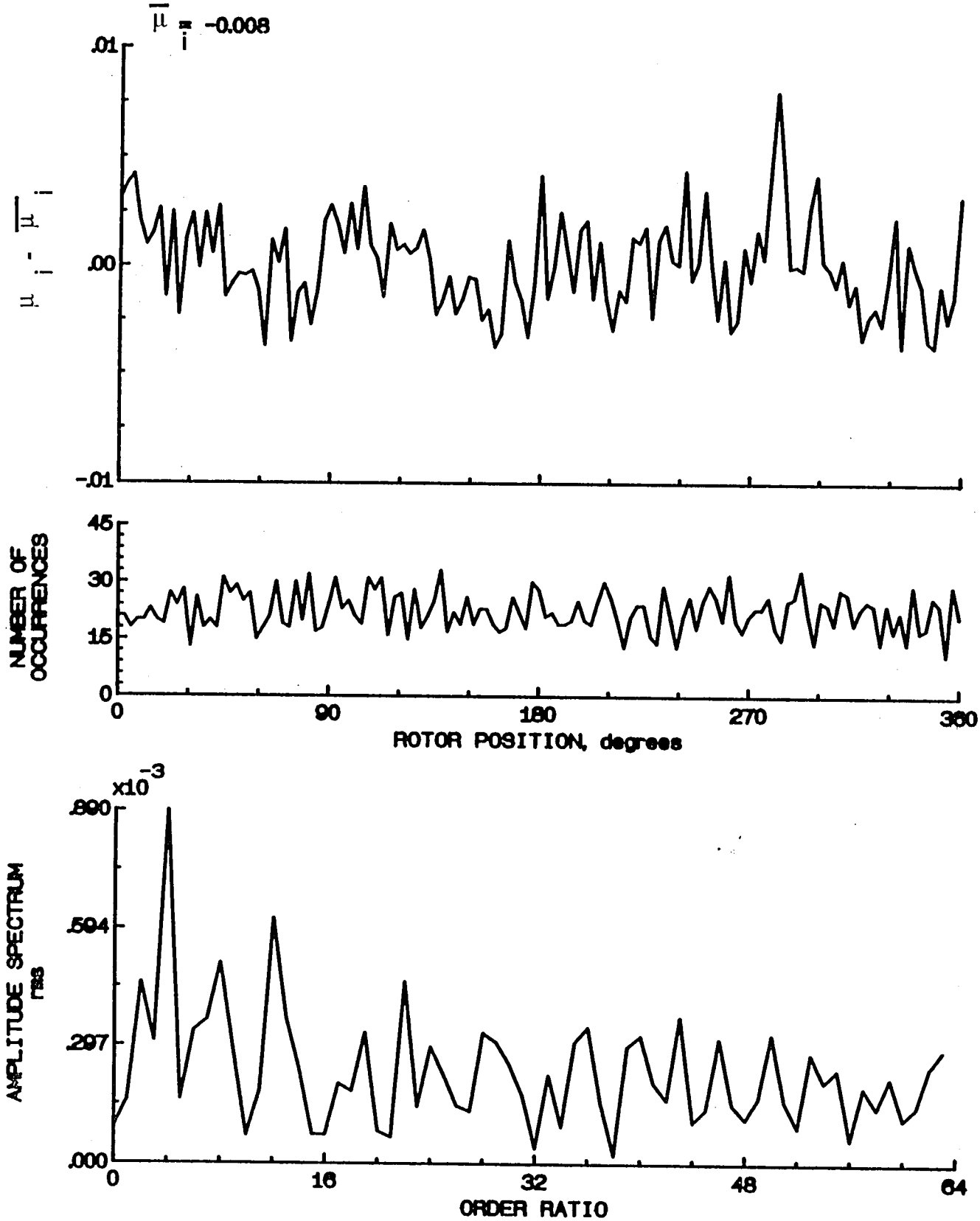


Figure 115.- Induced inflow velocity measured at 180 degrees and r/R of 1.02.

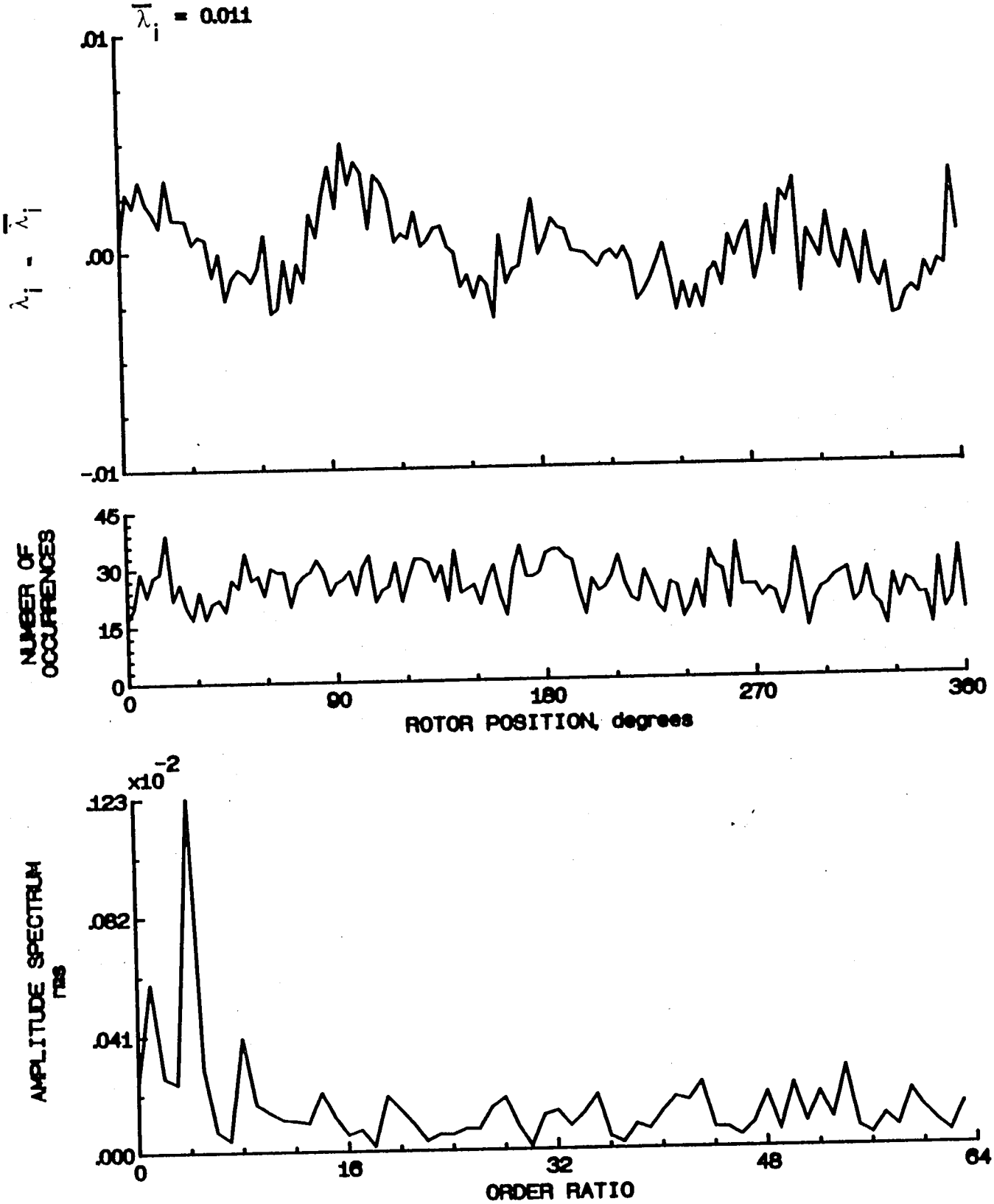


Figure 115.- Concluded.

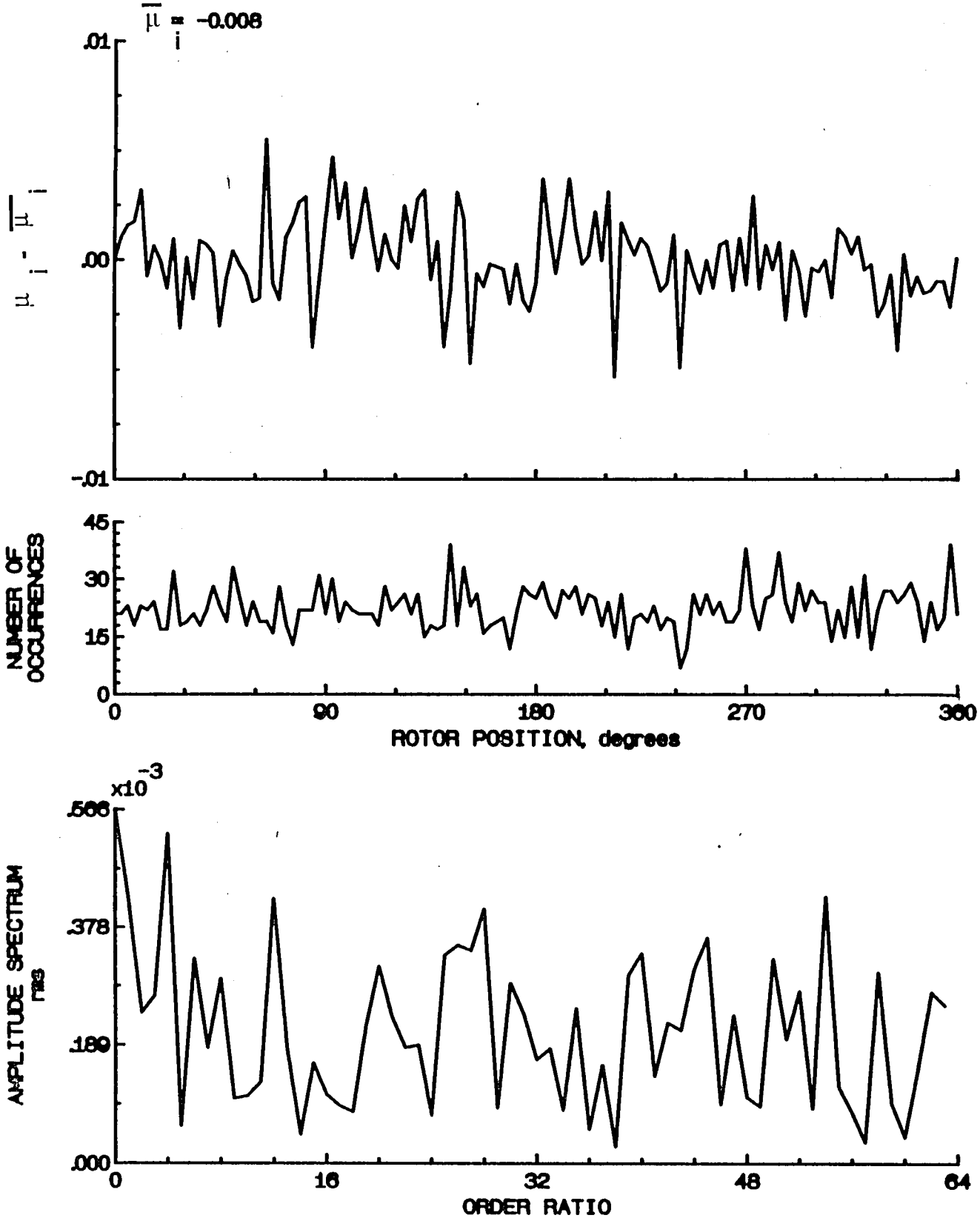


Figure 116.- Induced inflow velocity measured at 180 degrees and r/R of 1.04.

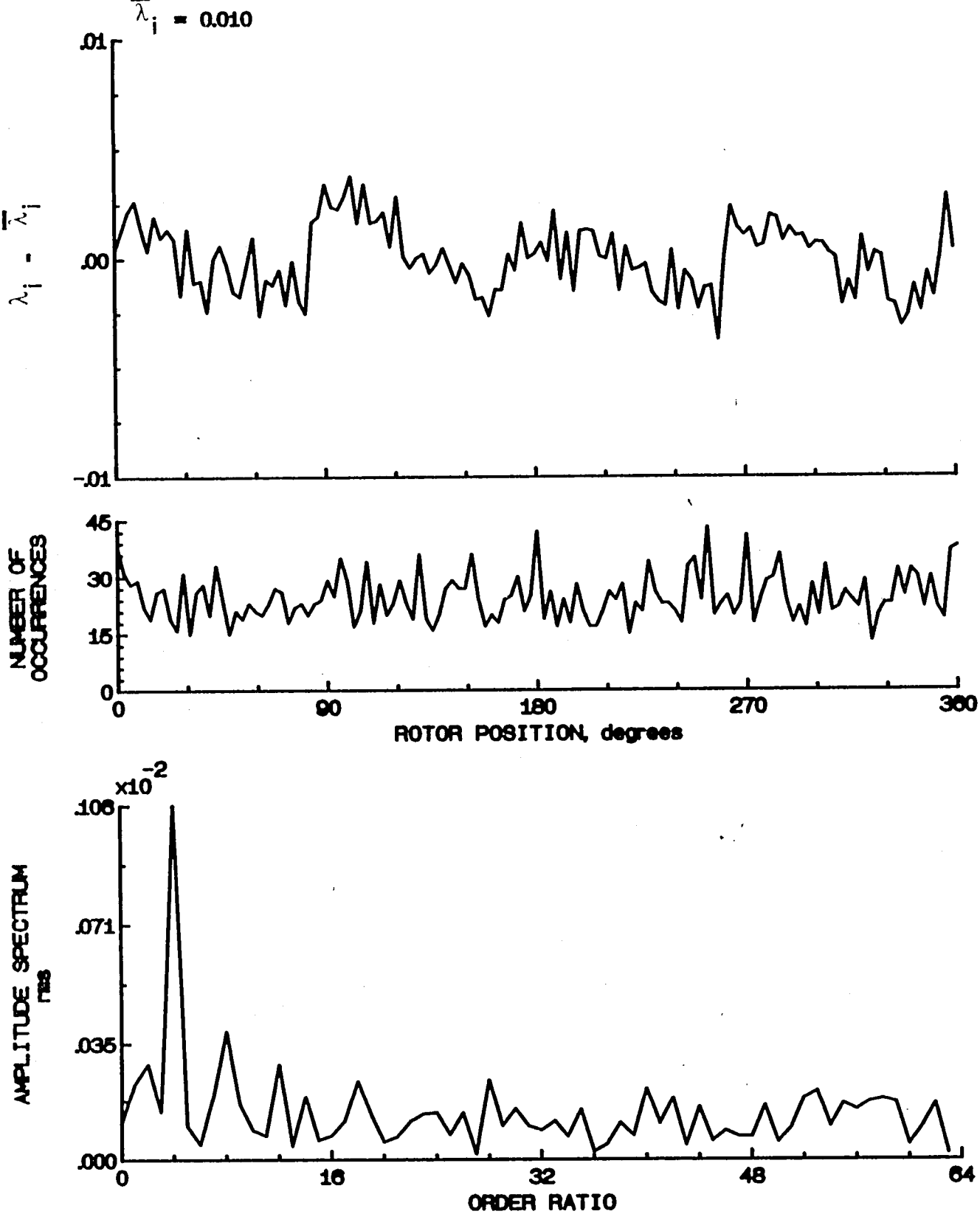


Figure 116.- Concluded.

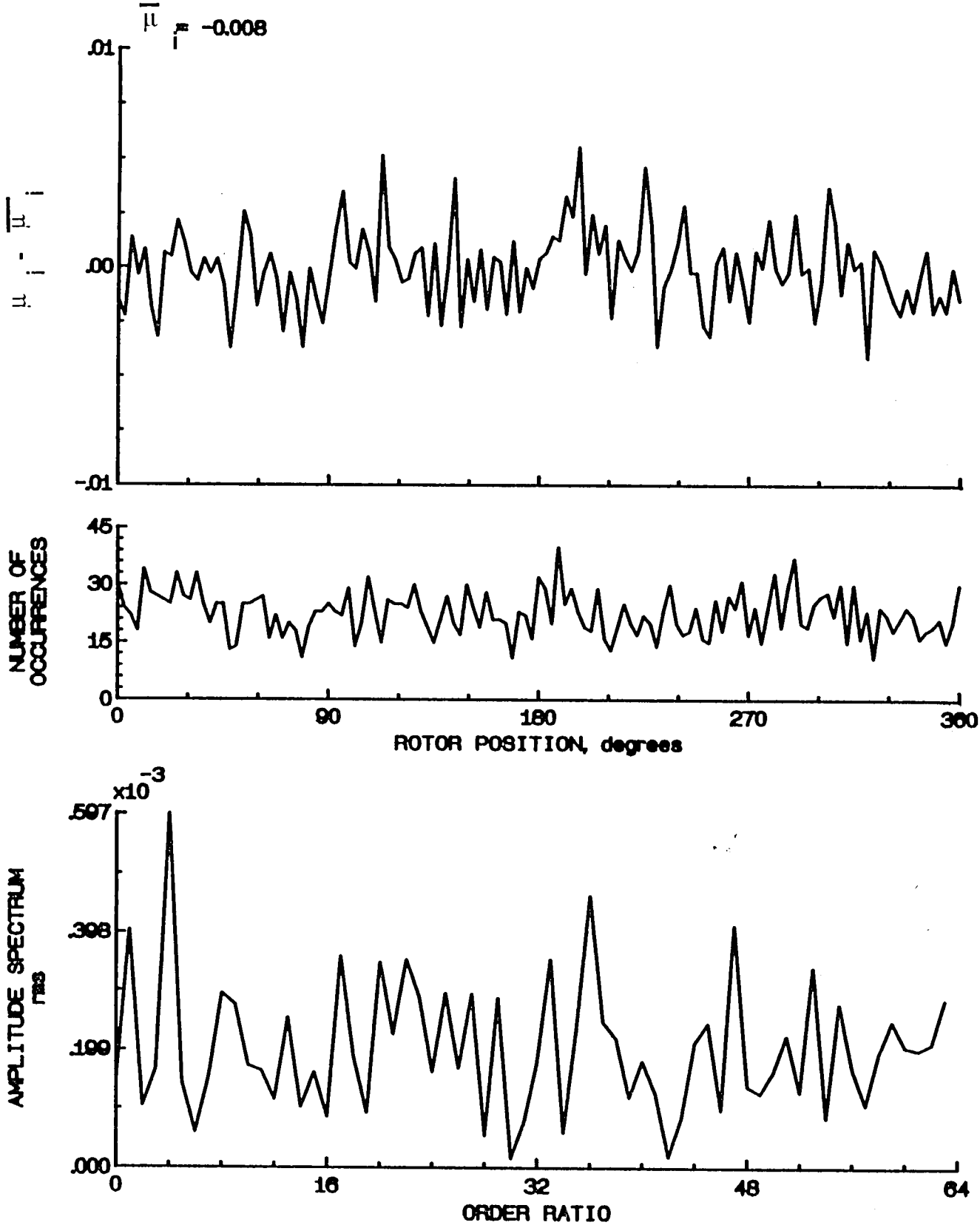


Figure 117.- Induced inflow velocity measured at 180 degrees and r/R of 1.10.

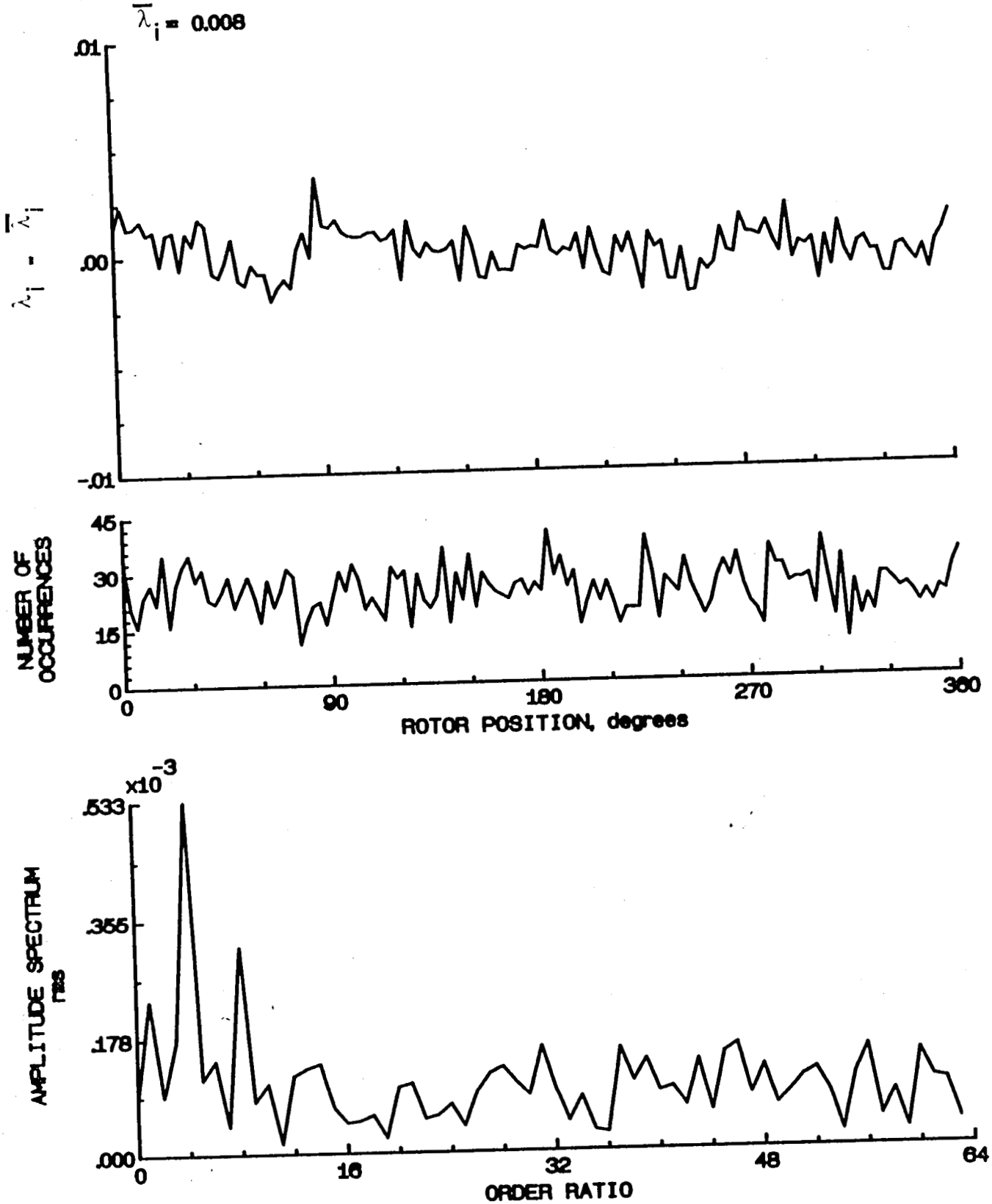


Figure 117.- Concluded.

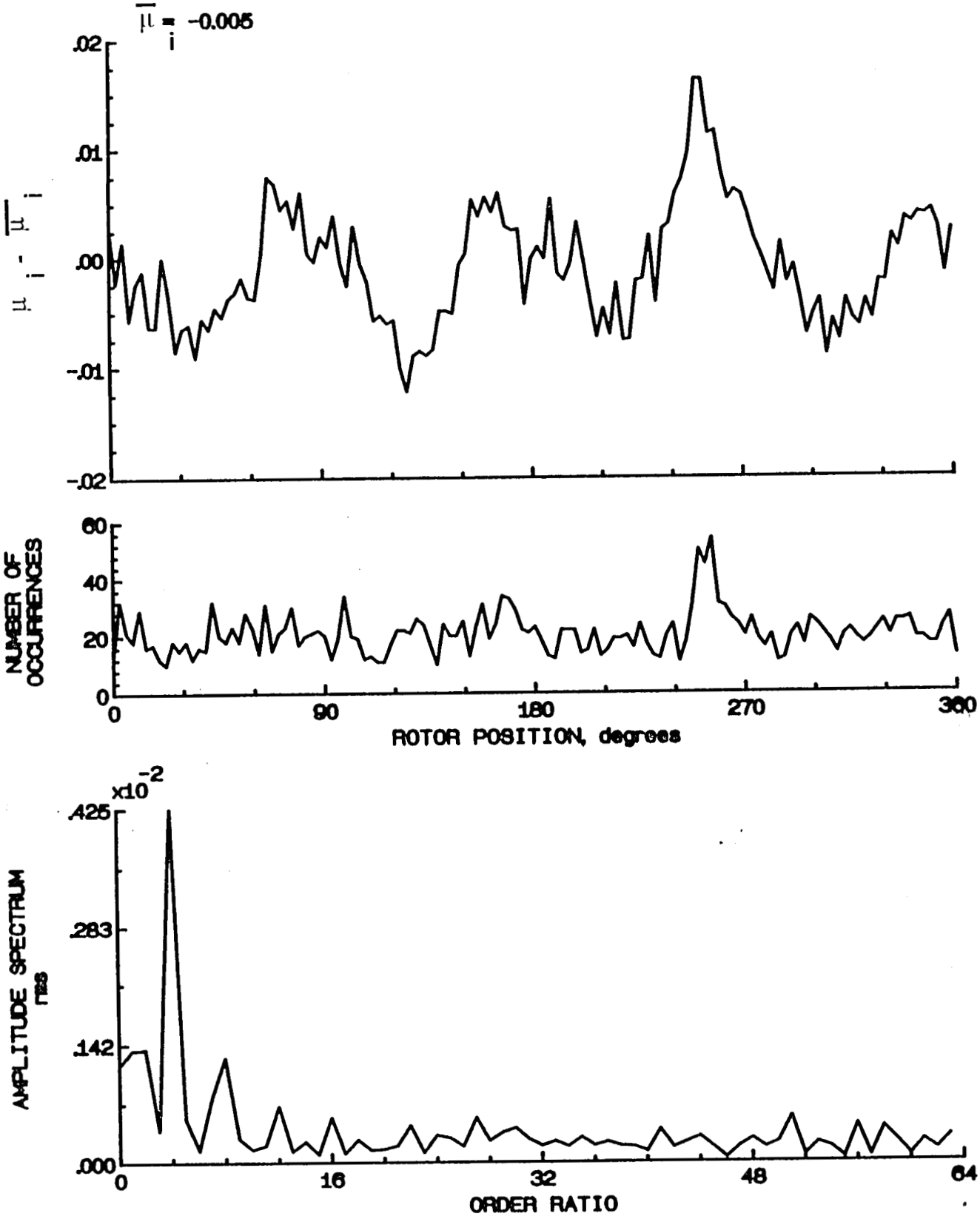
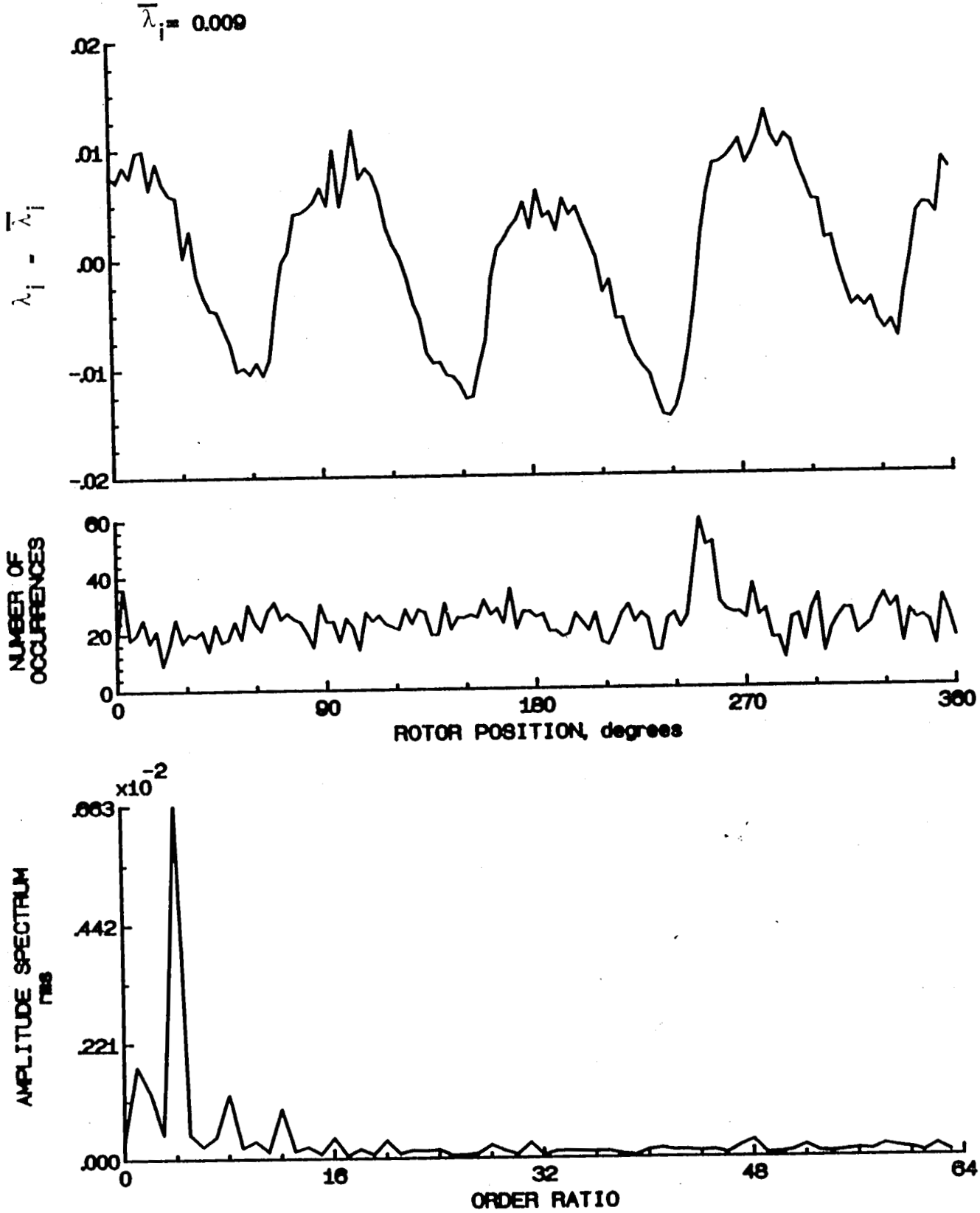


Figure 118.- Induced inflow velocity measured at 210 degrees and r/R of 0.20.



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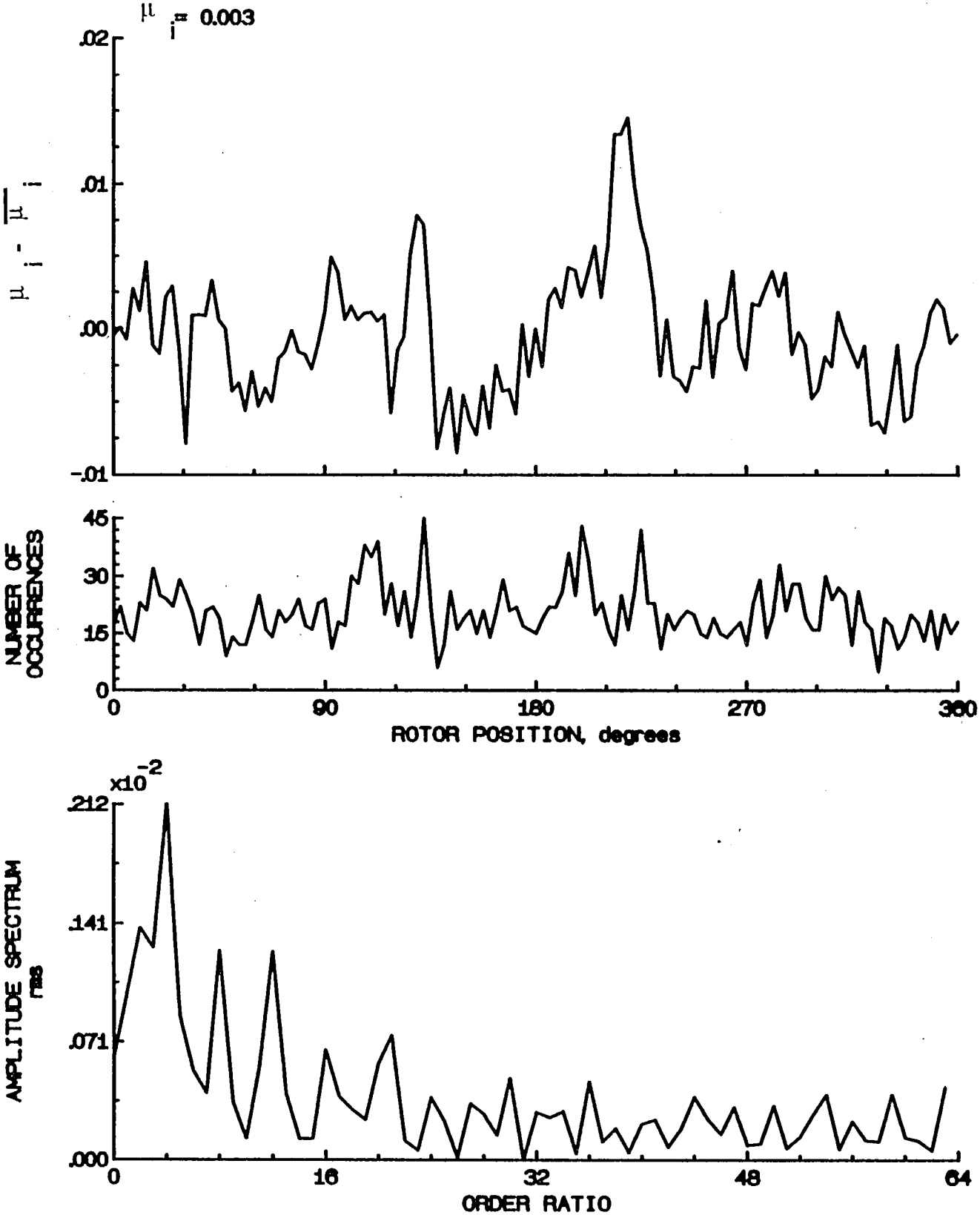
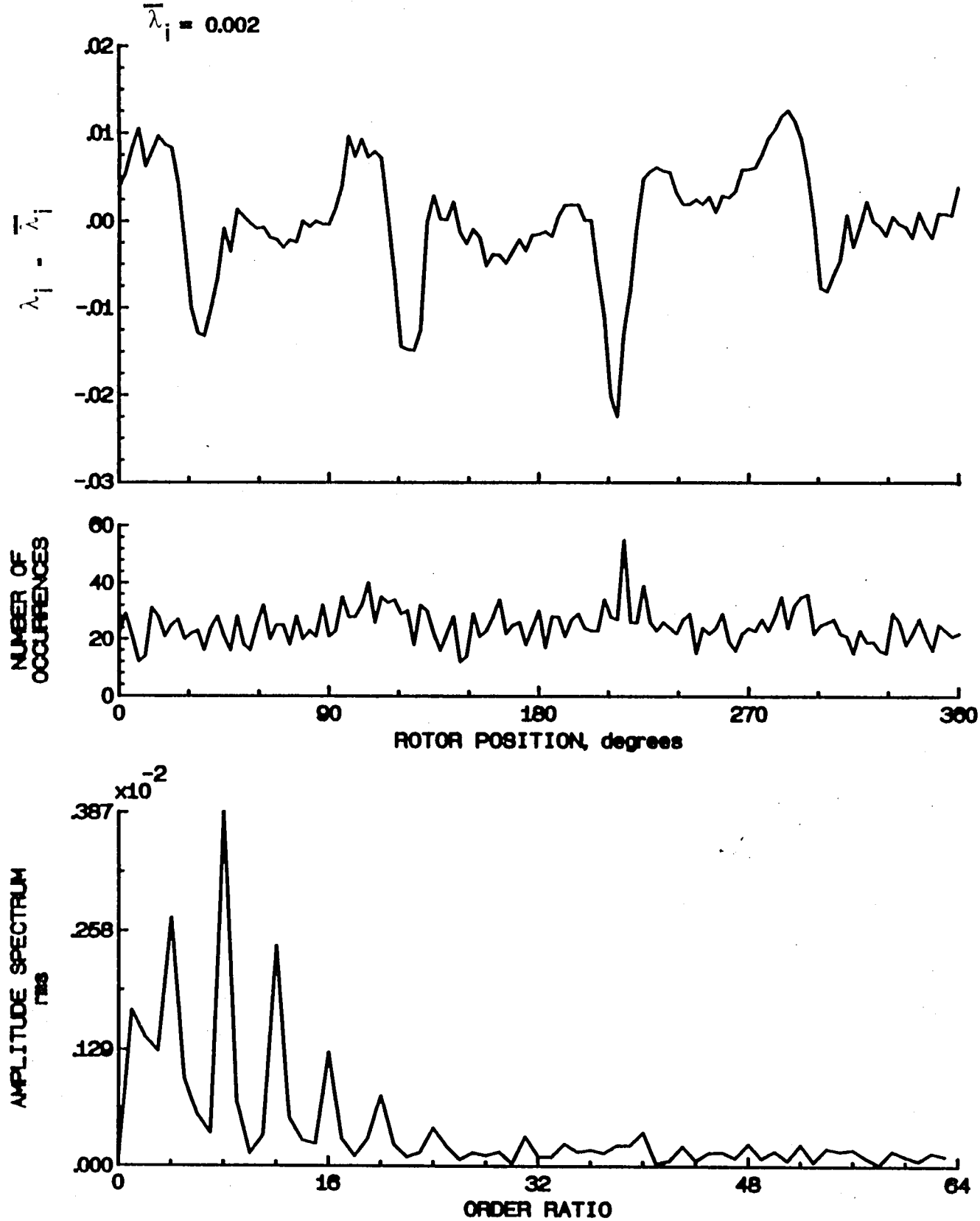


Figure 119.- Induced inflow velocity measured at 210 degrees and r/R of 0.40.



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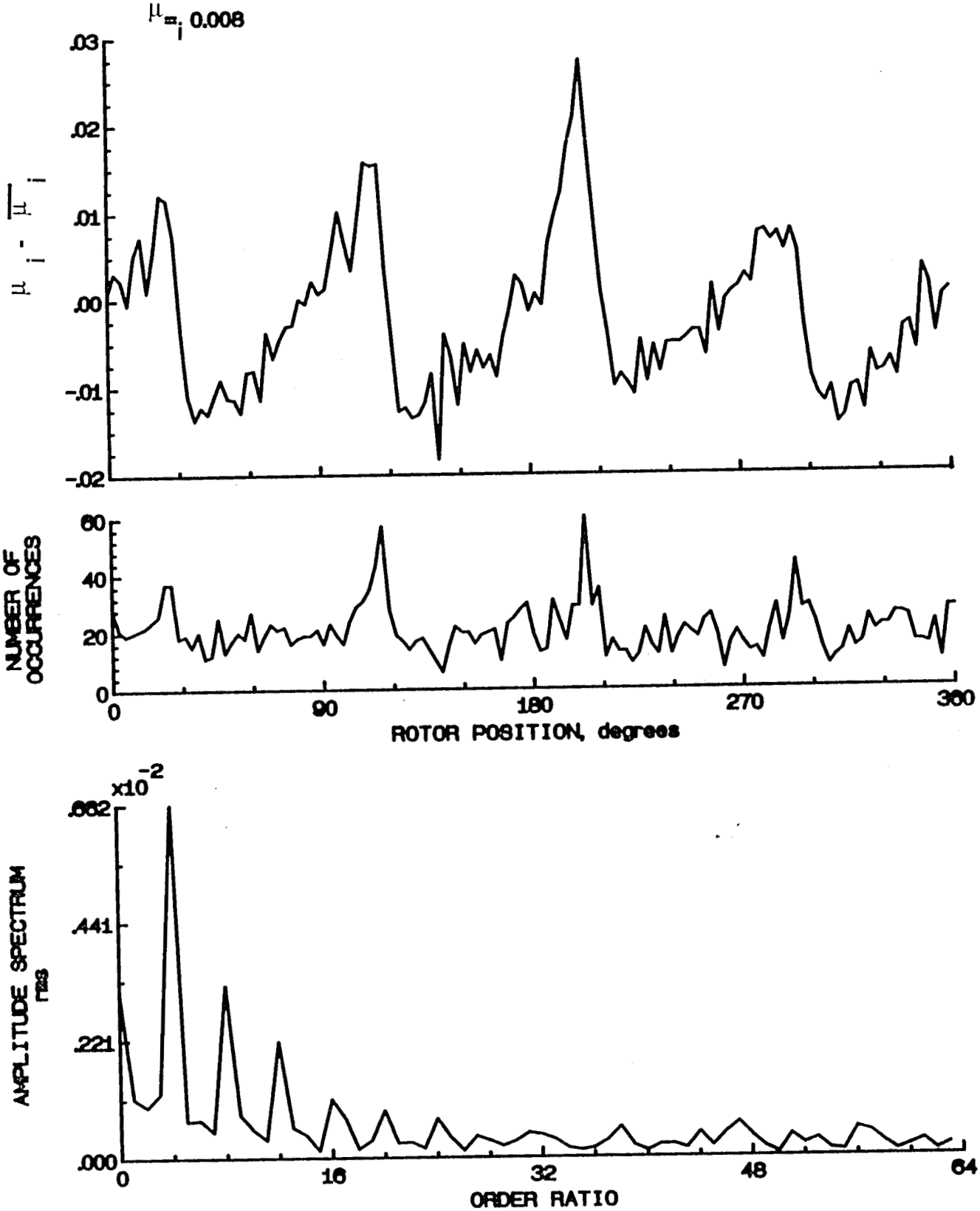
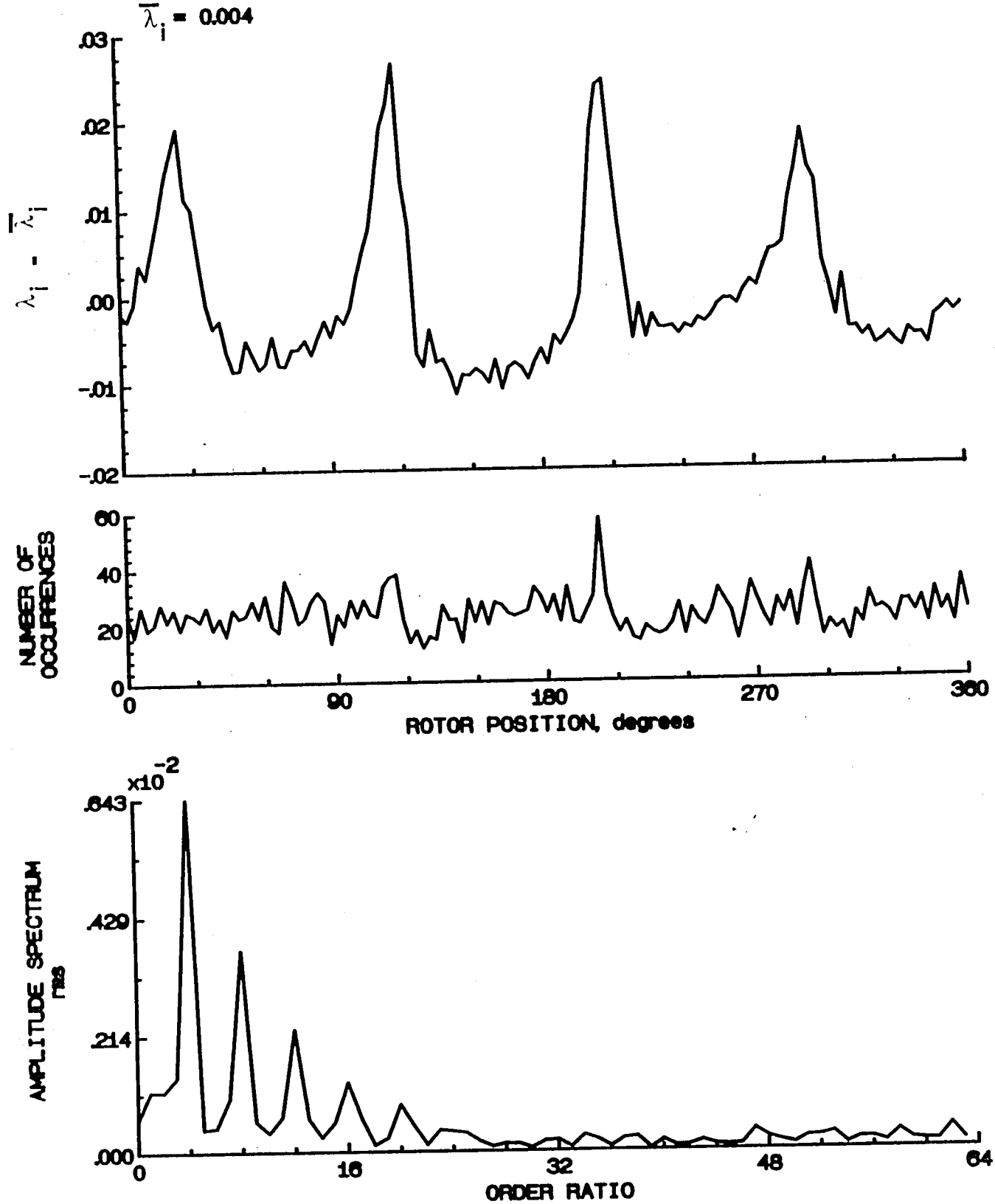


Figure 120.- Induced inflow velocity measured at 210 degrees and r/R of 0.50.



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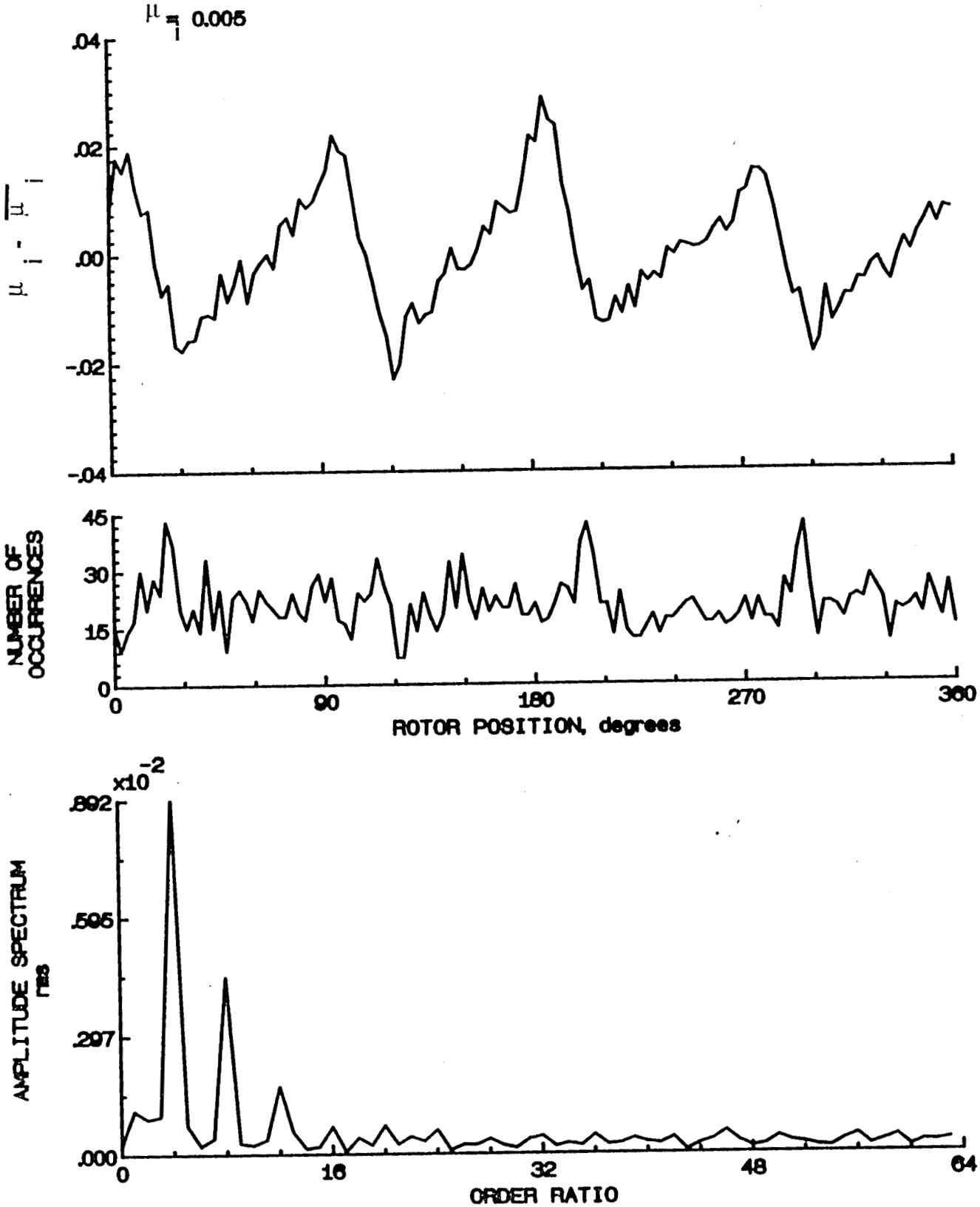
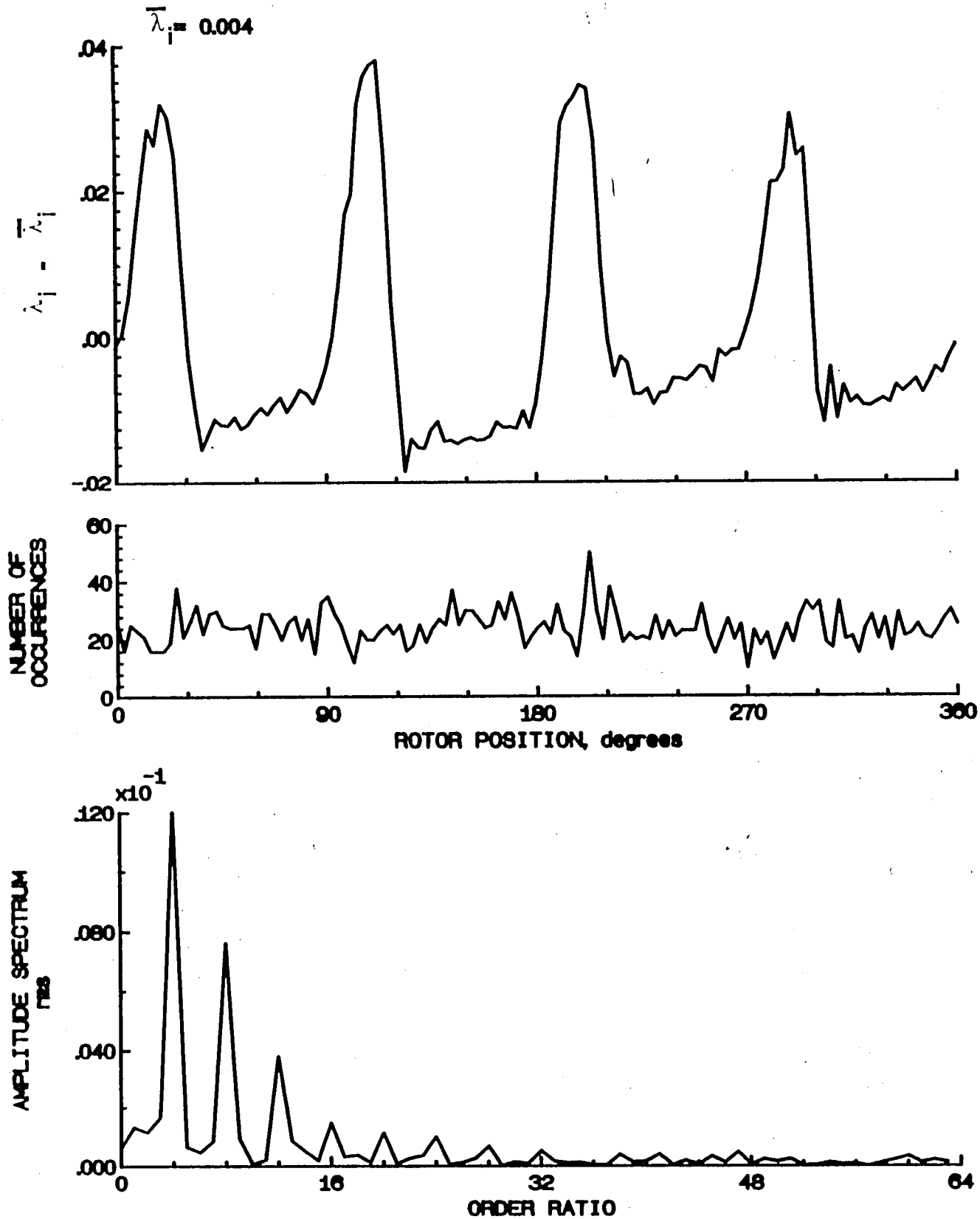


Figure 121.- Induced inflow velocity measured at 210 degrees and r/R of 0.60.



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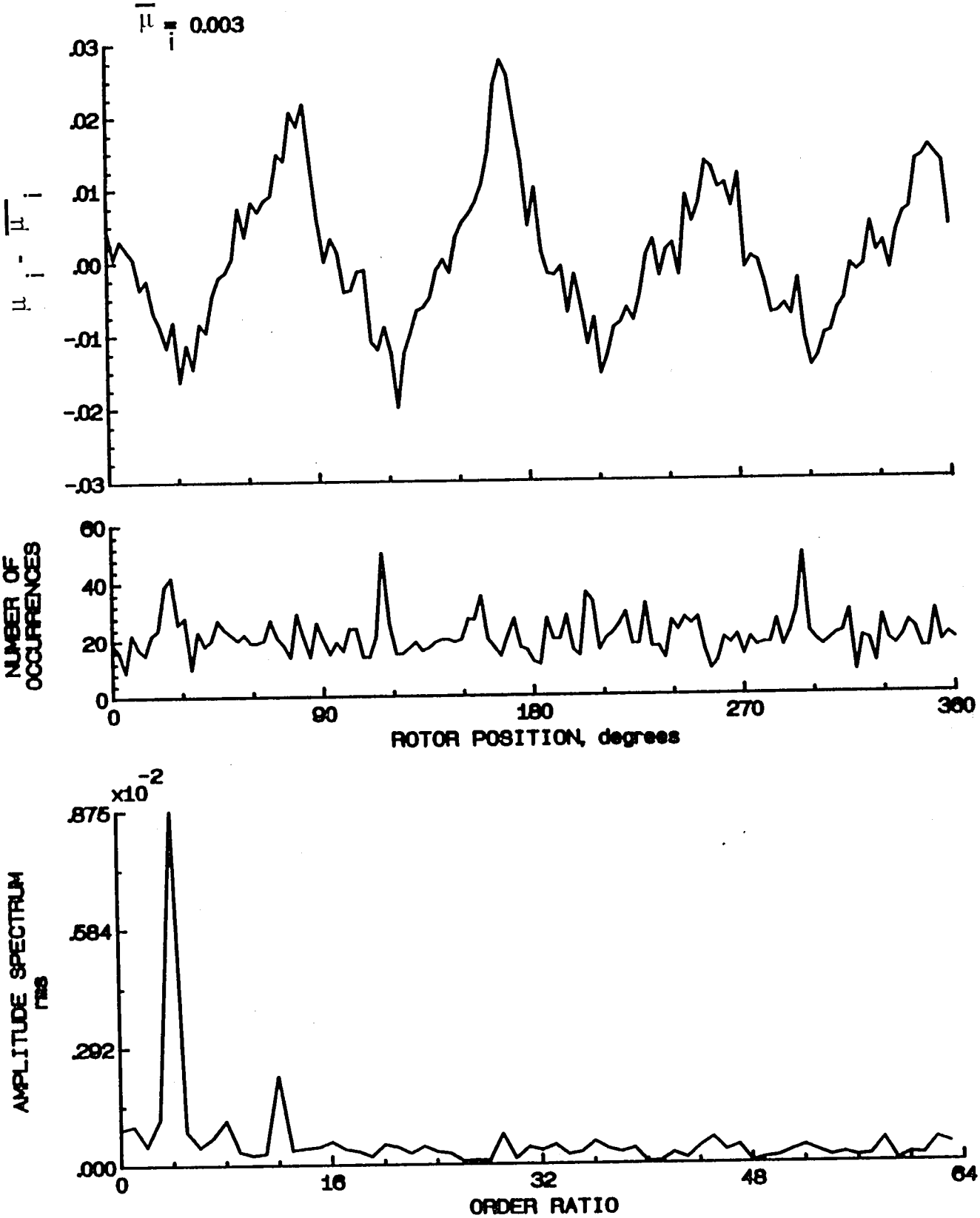
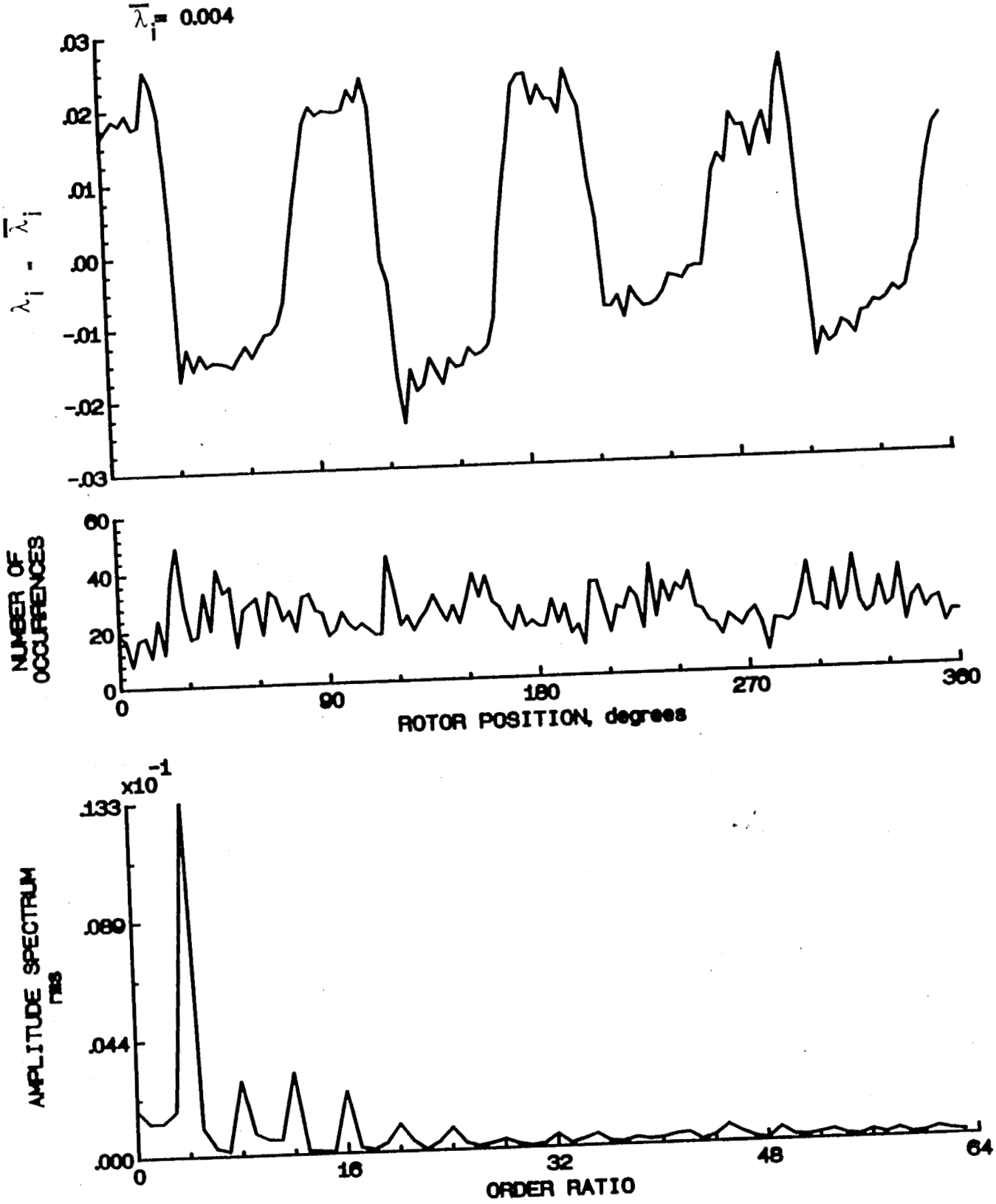


Figure 122.- Induced inflow velocity measured at 210 degrees and r/R of 0.70.



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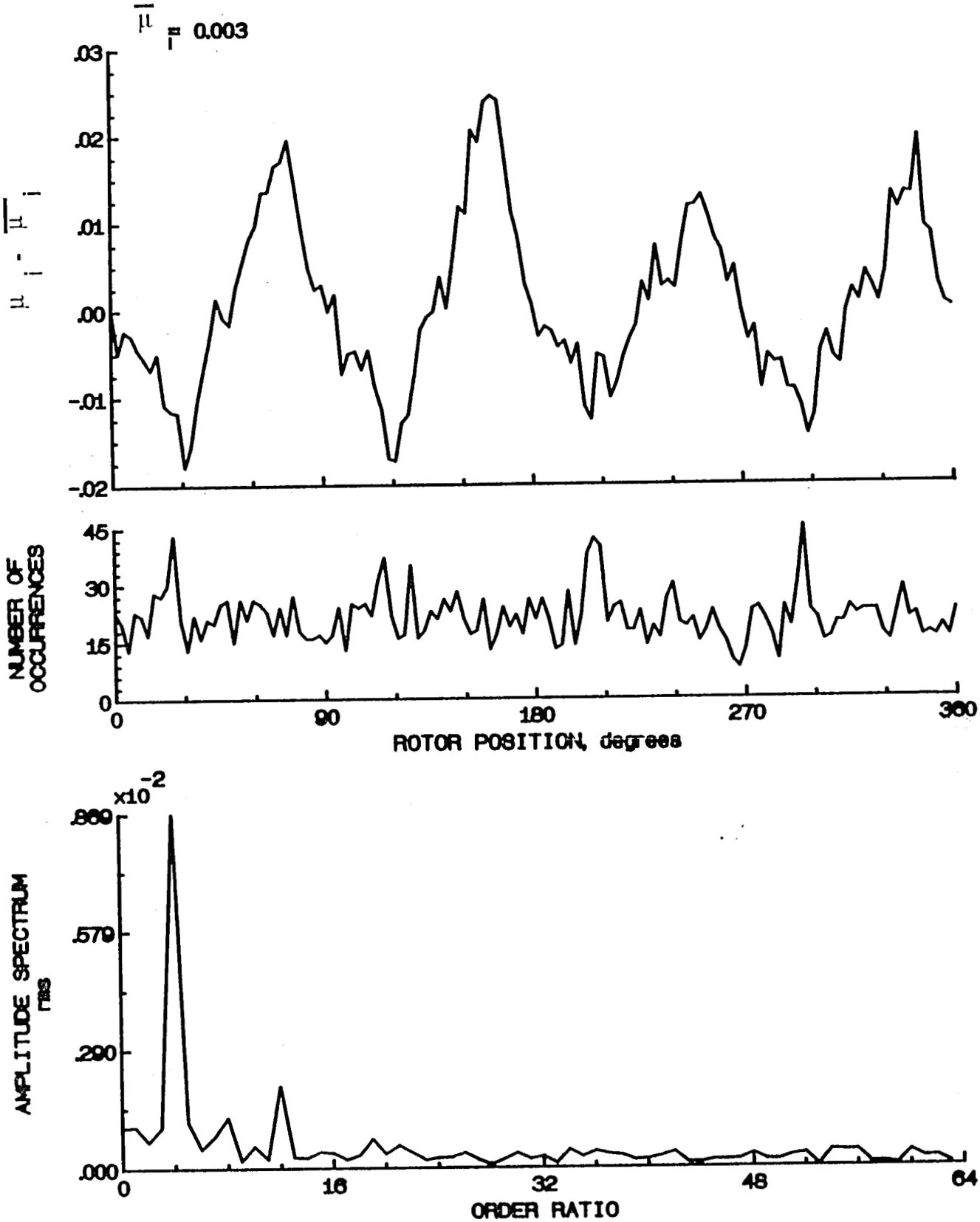


Figure 123.- Induced inflow velocity measured at 210 degrees and r/R of 0.74.

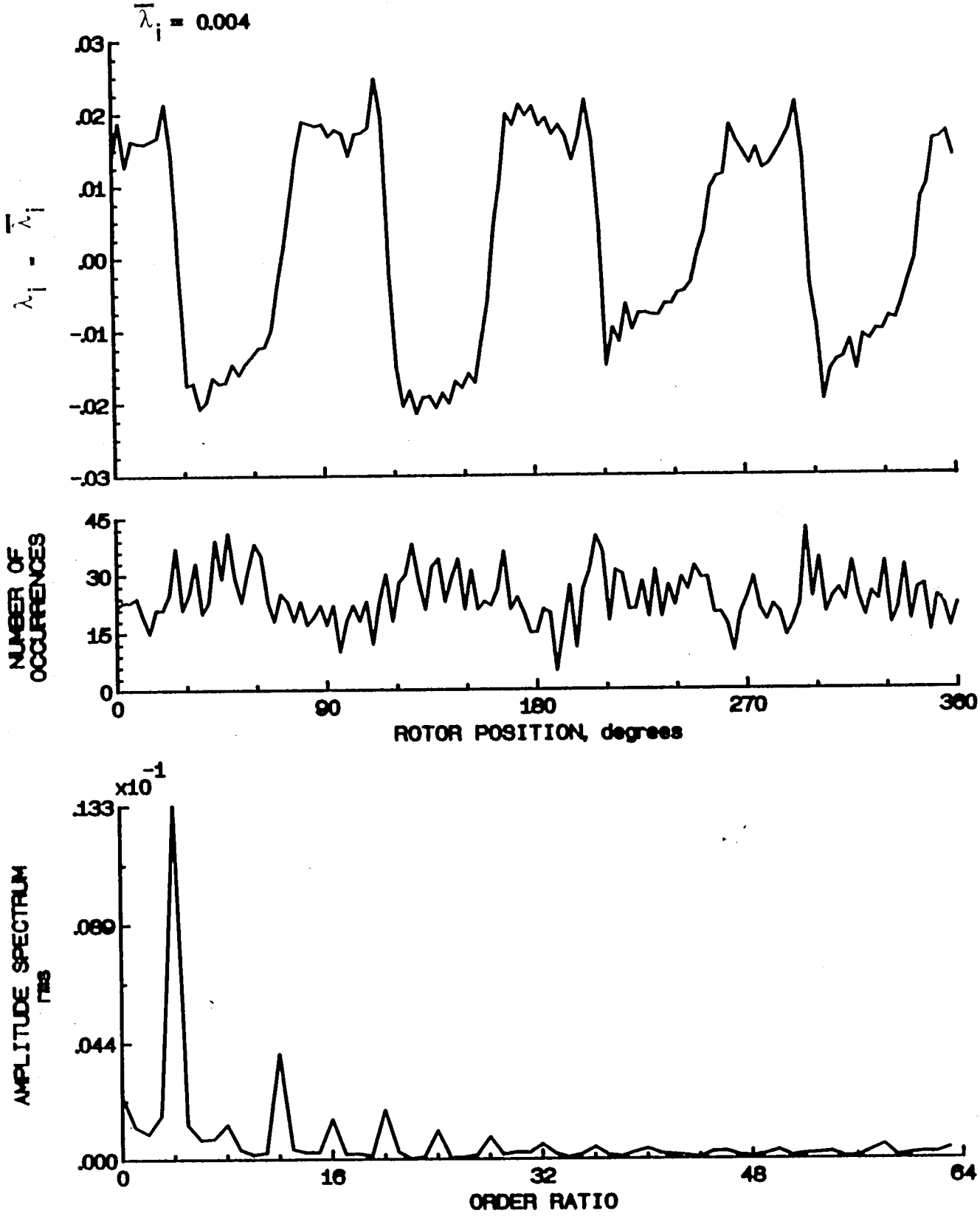


Figure 123.- Concluded.

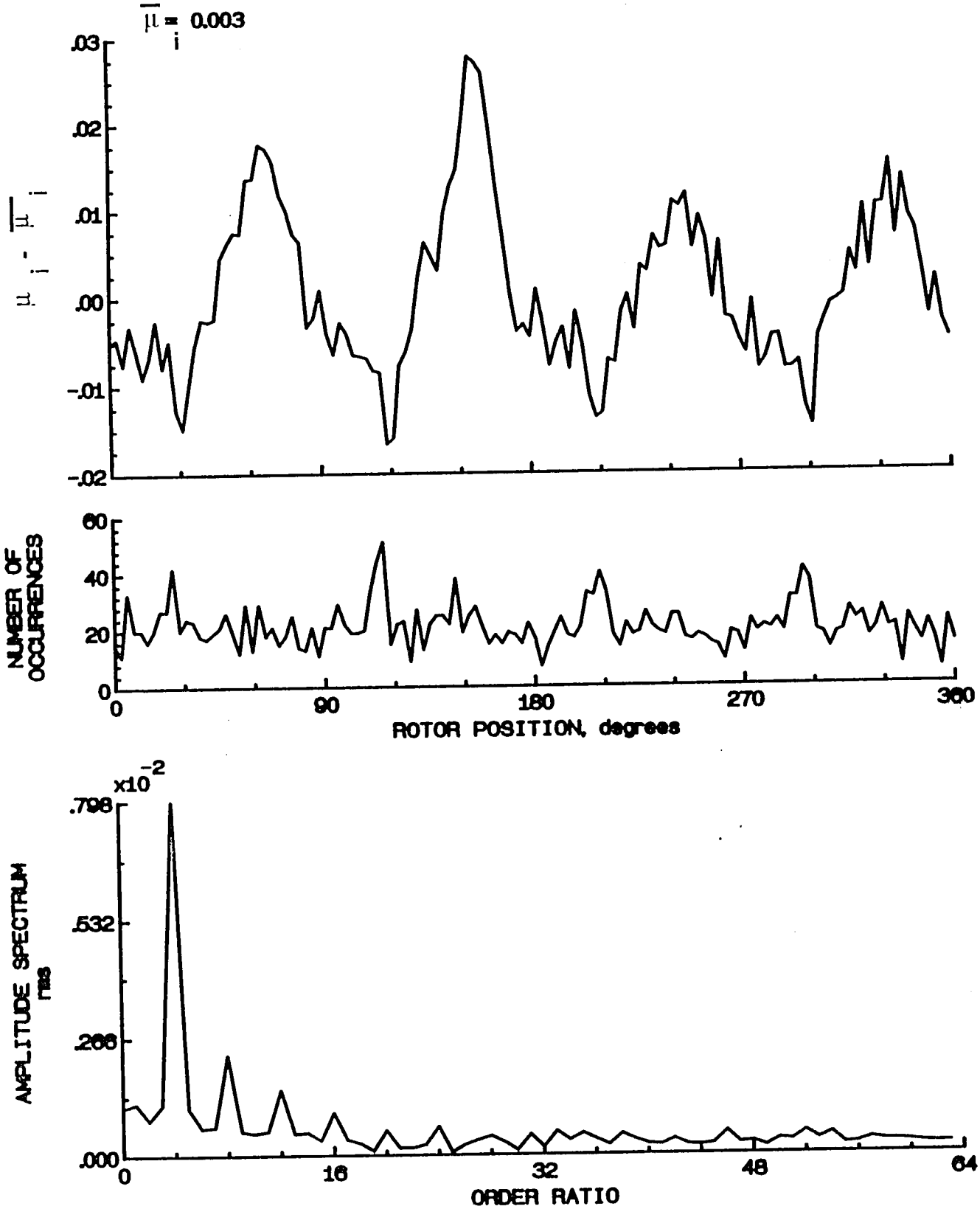
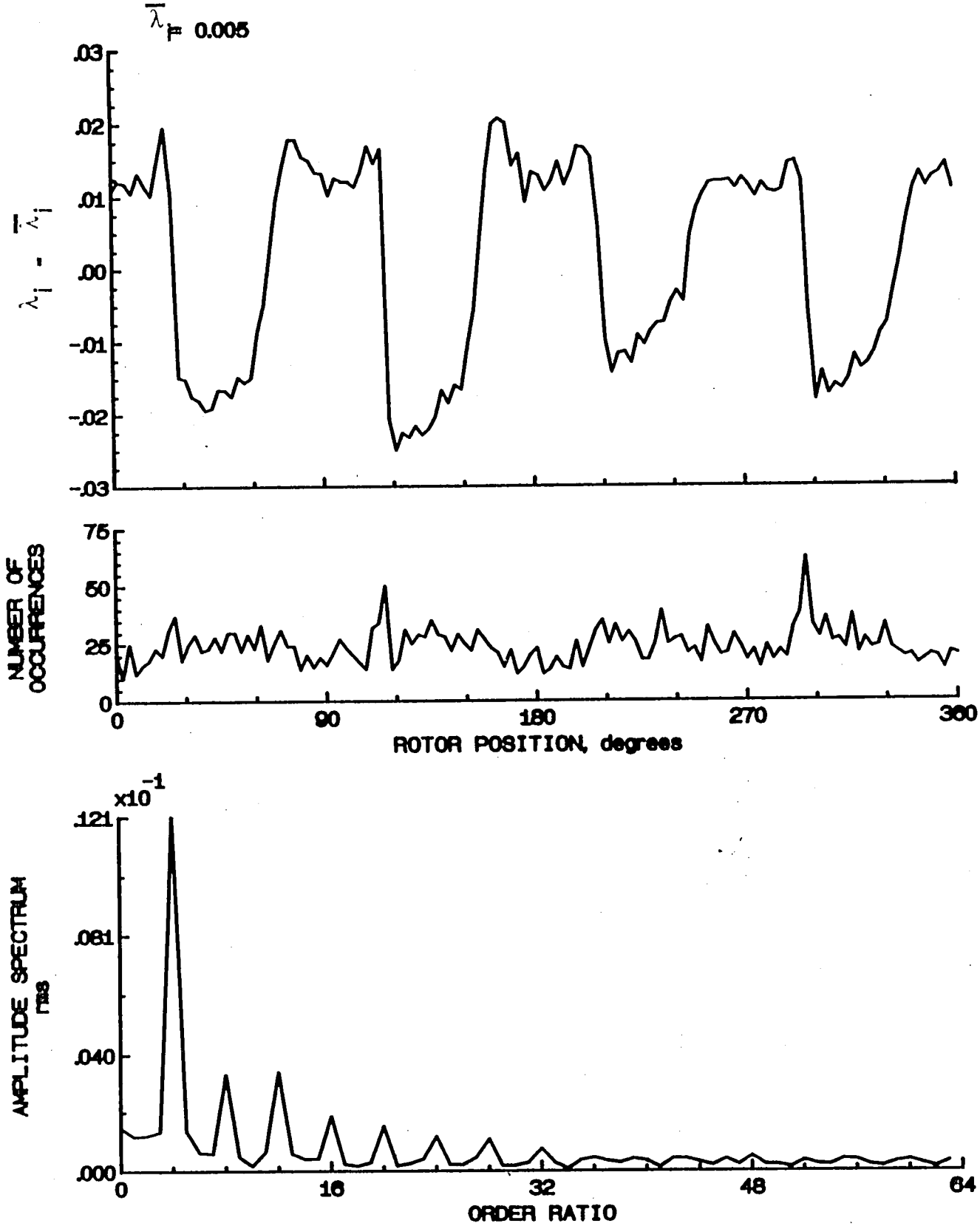


Figure 124.- Induced inflow velocity measured at 210 degrees and r/R of 0.78.



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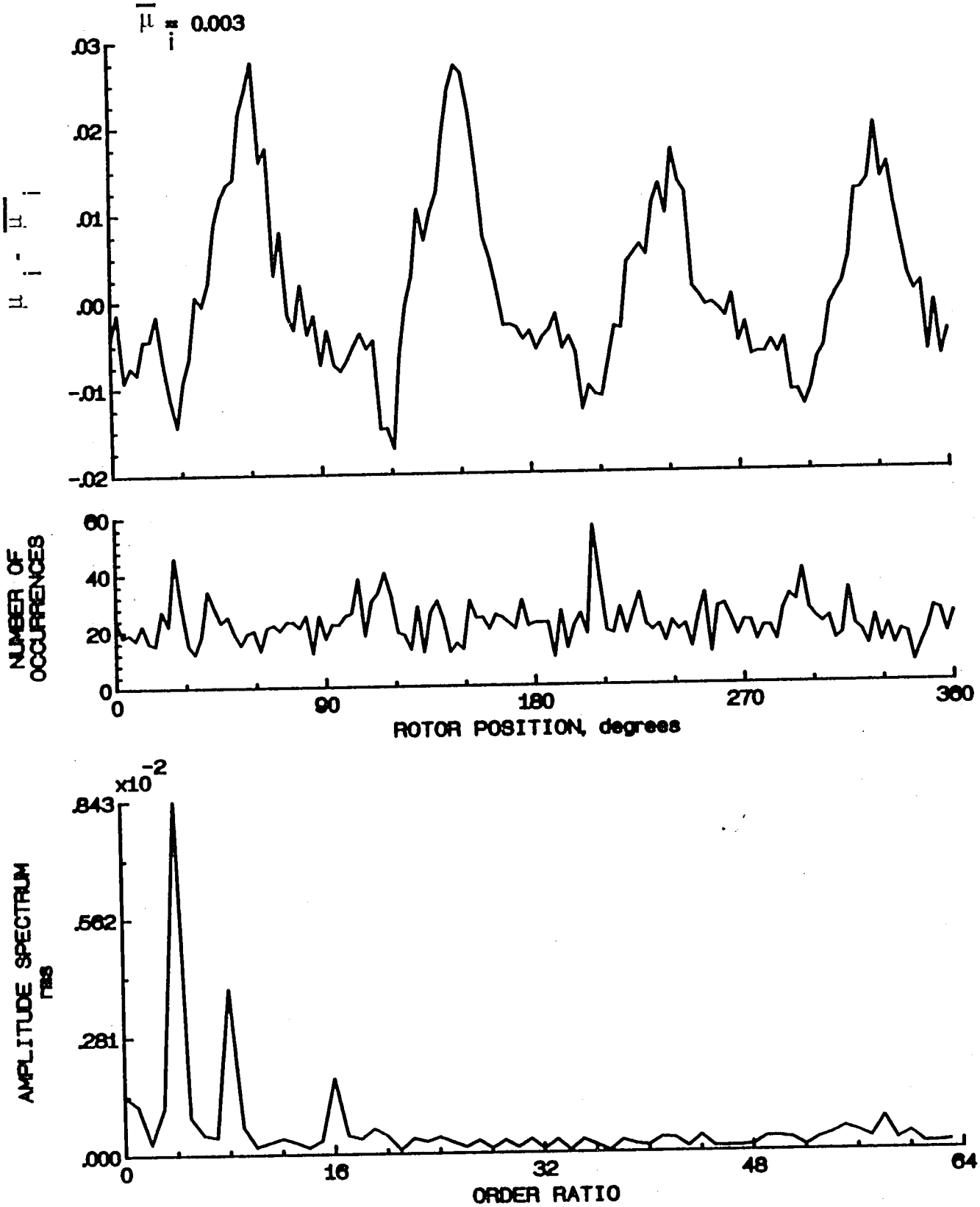
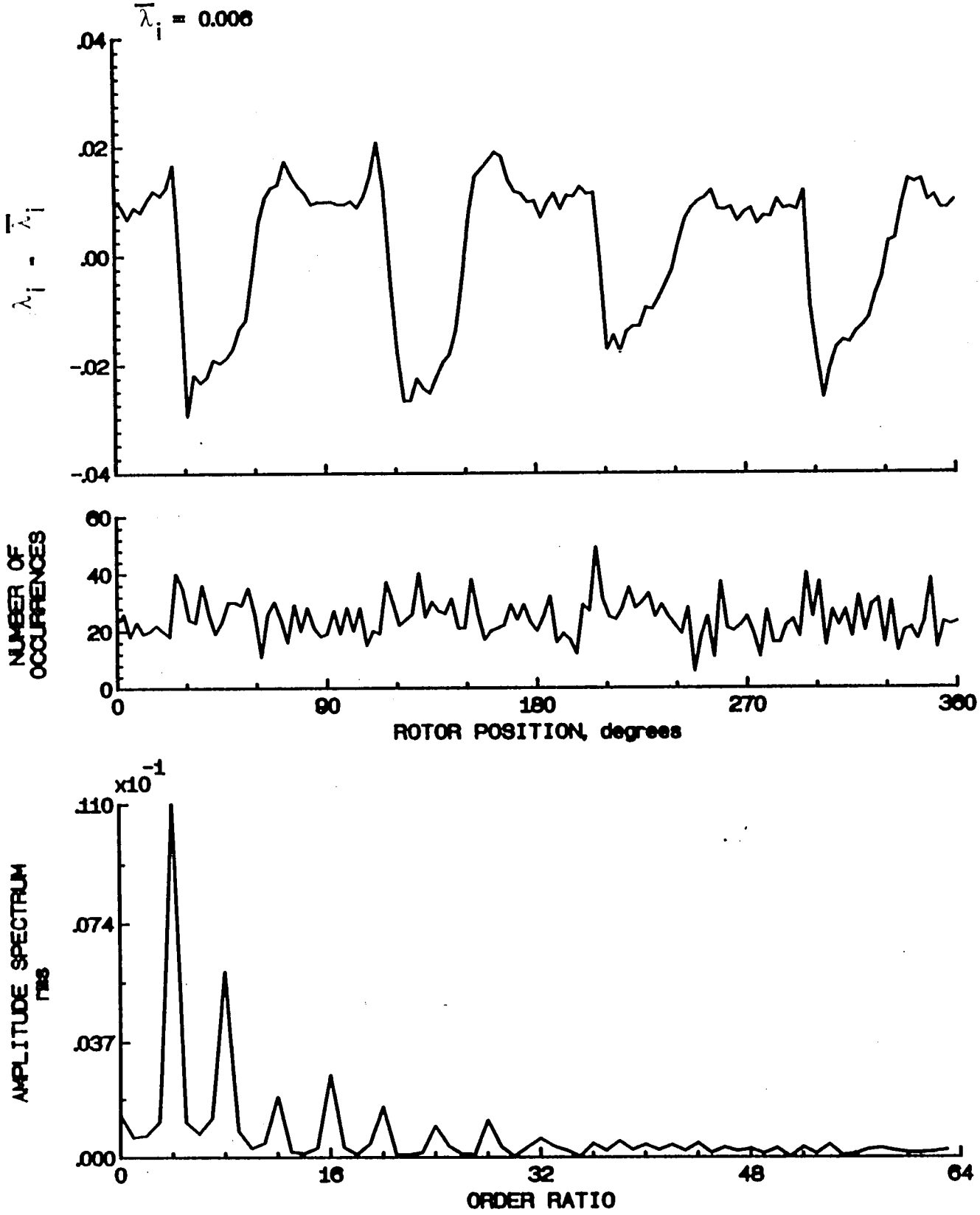


Figure 125.- Induced inflow velocity measured at 210 degrees and r/R of 0.82.



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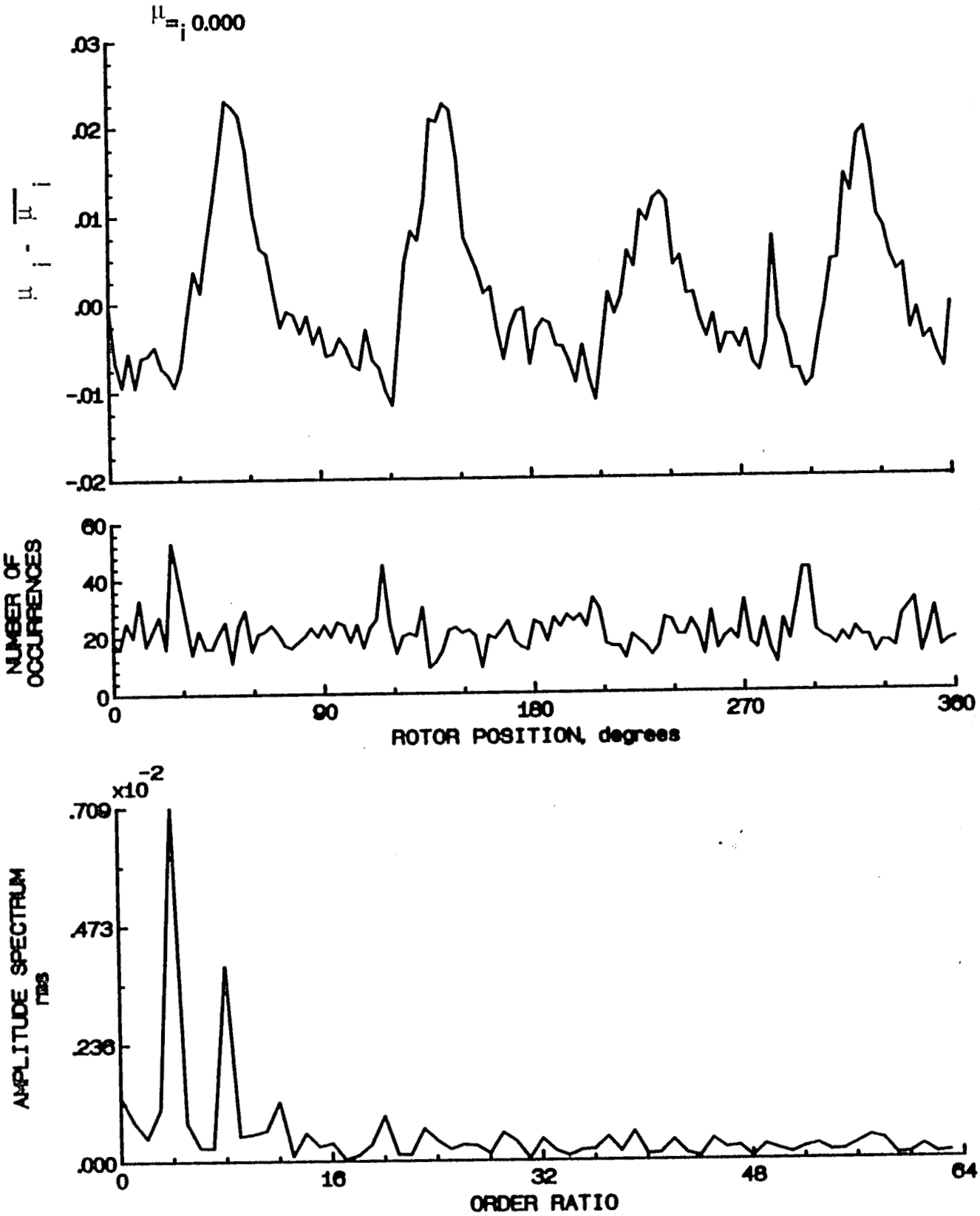
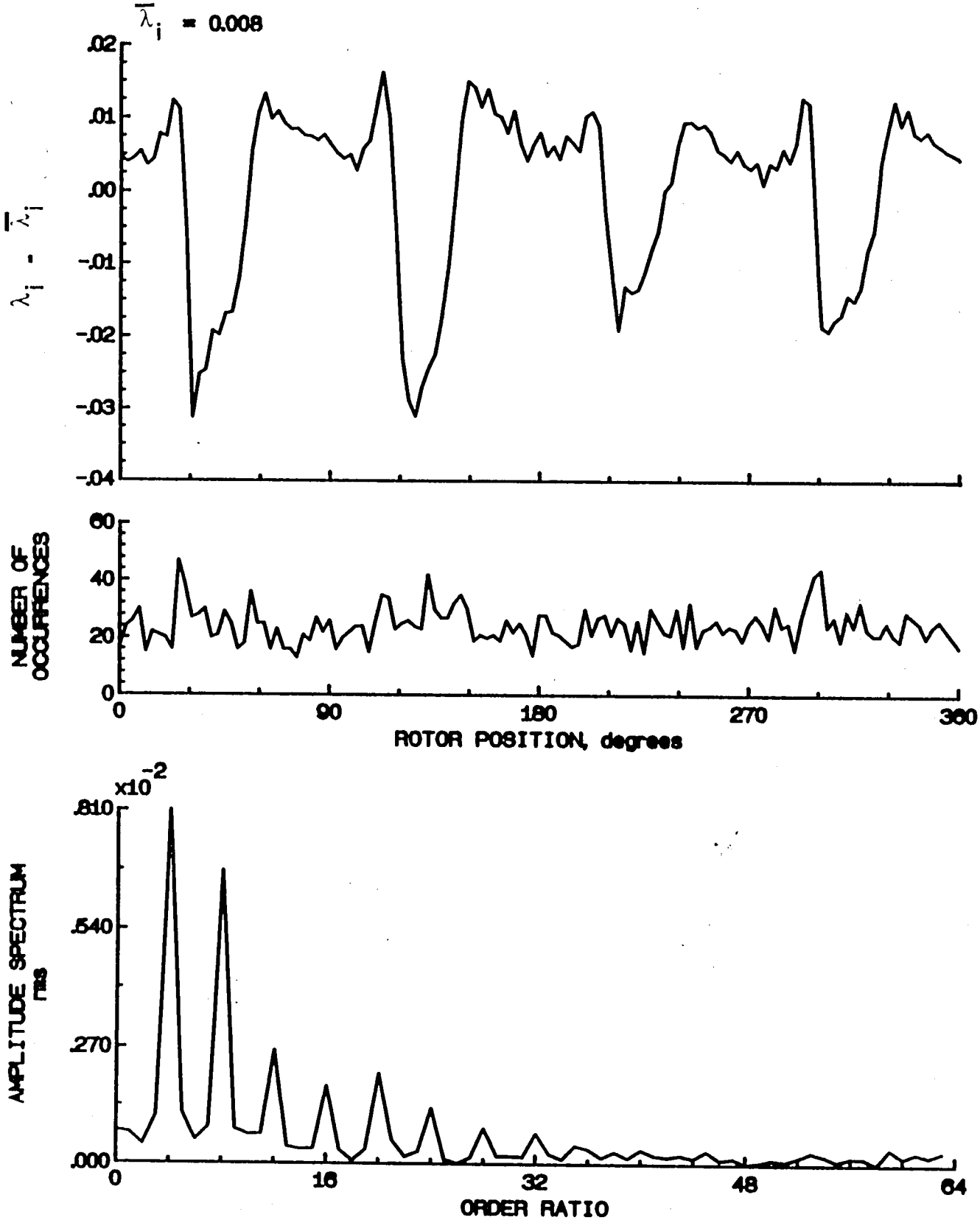


Figure 126.- Induced inflow velocity measured at 210 degrees and r/R of 0.86.



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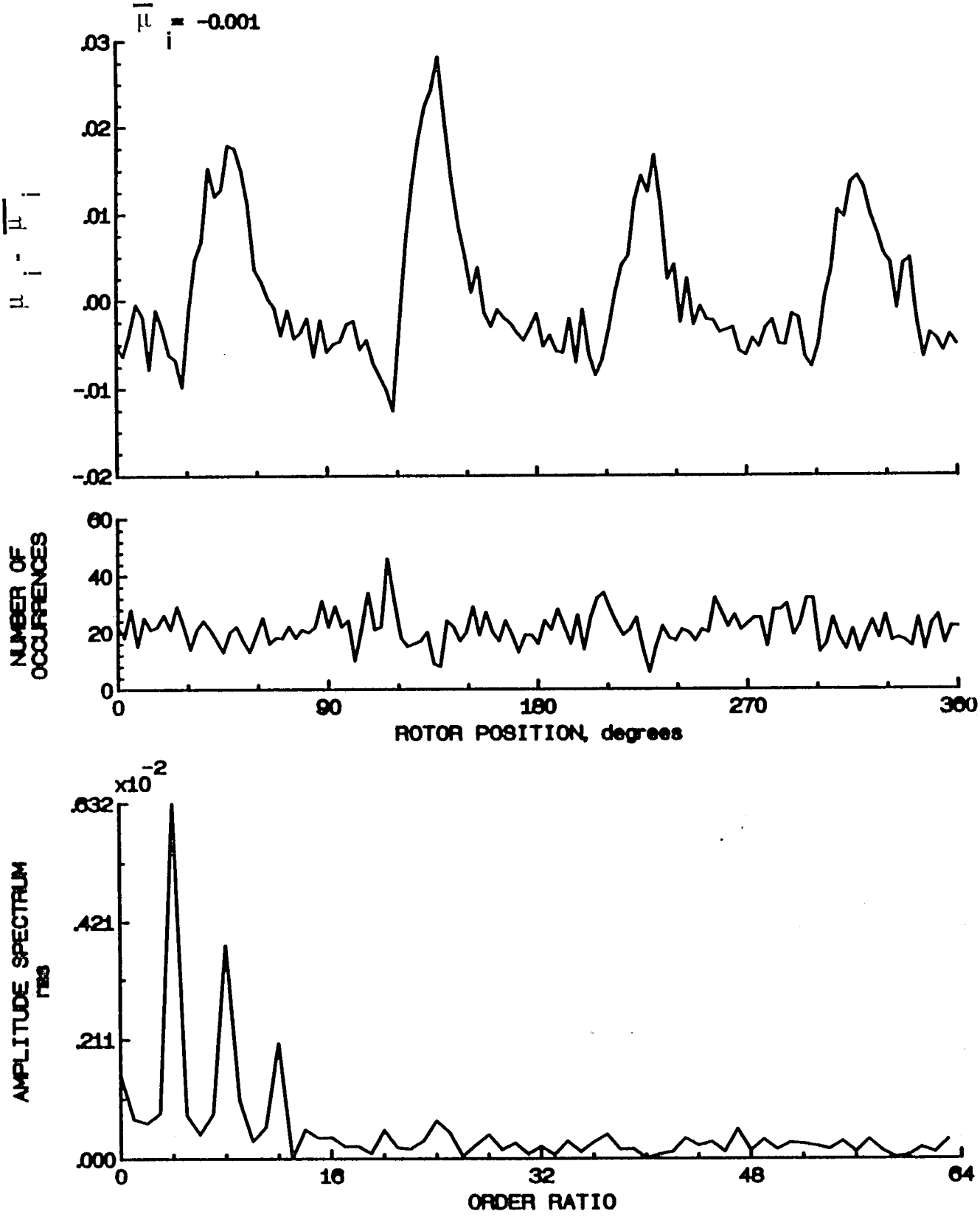
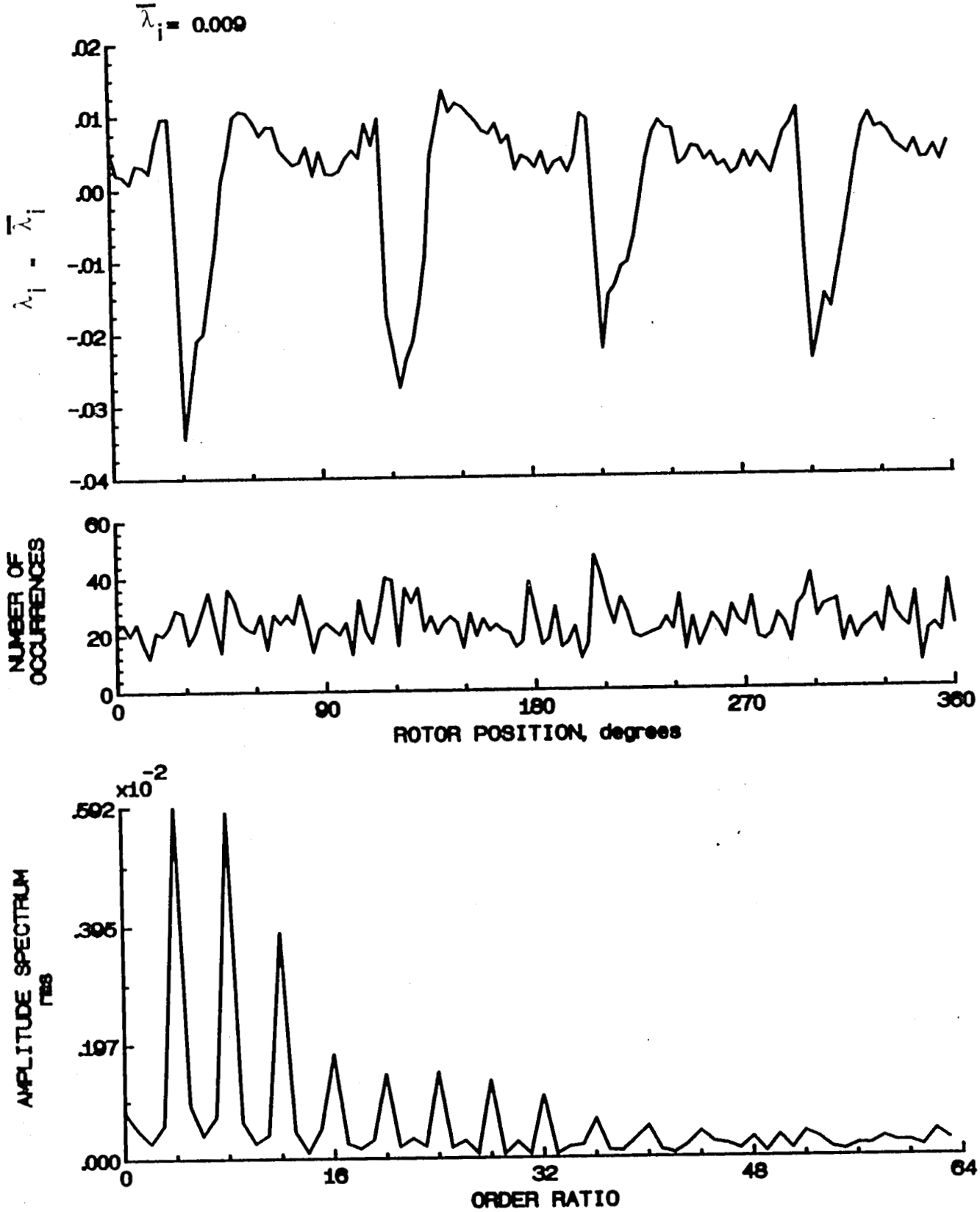


Figure 127.- Induced inflow velocity measured at 210 degrees and r/R of 0.90.



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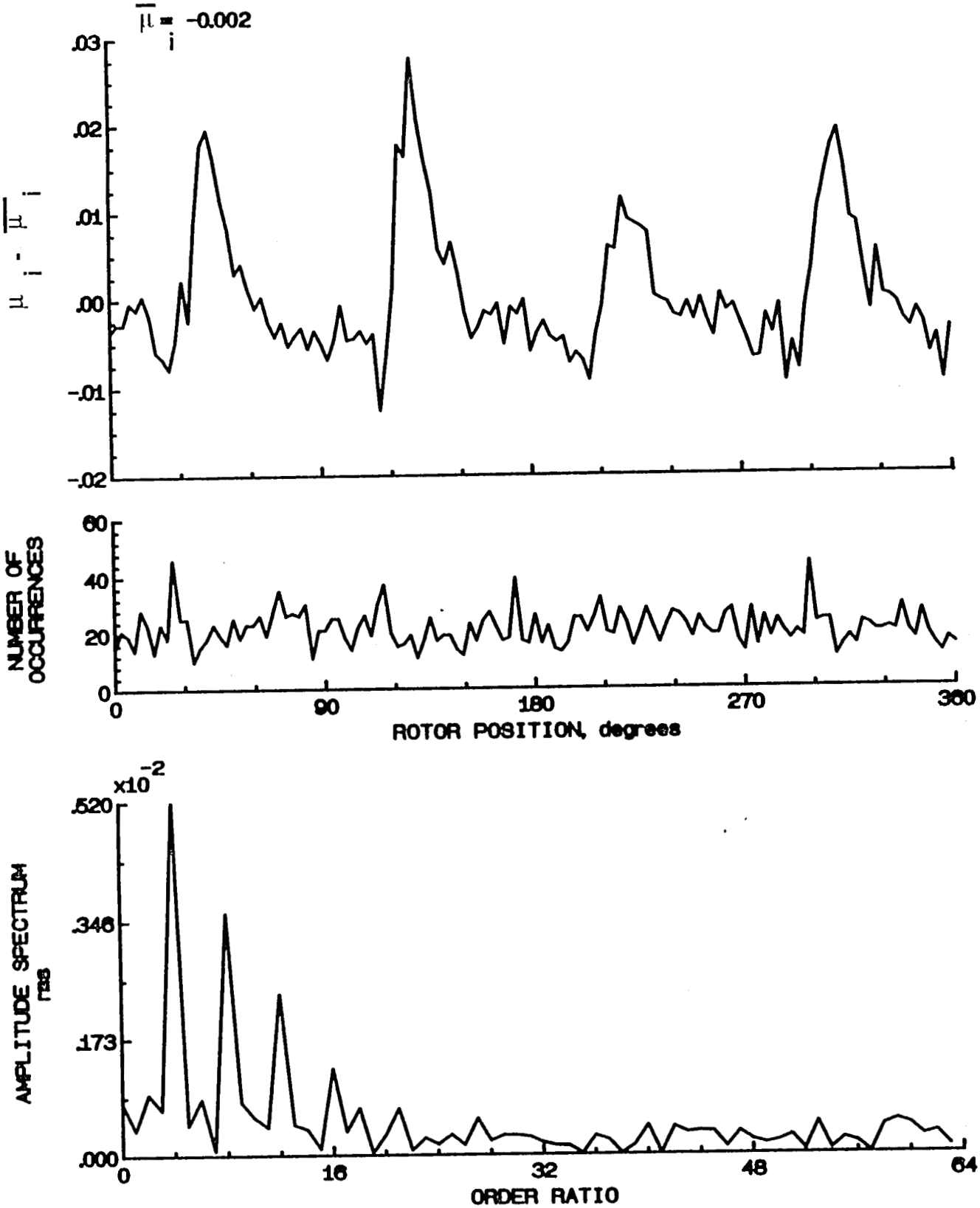
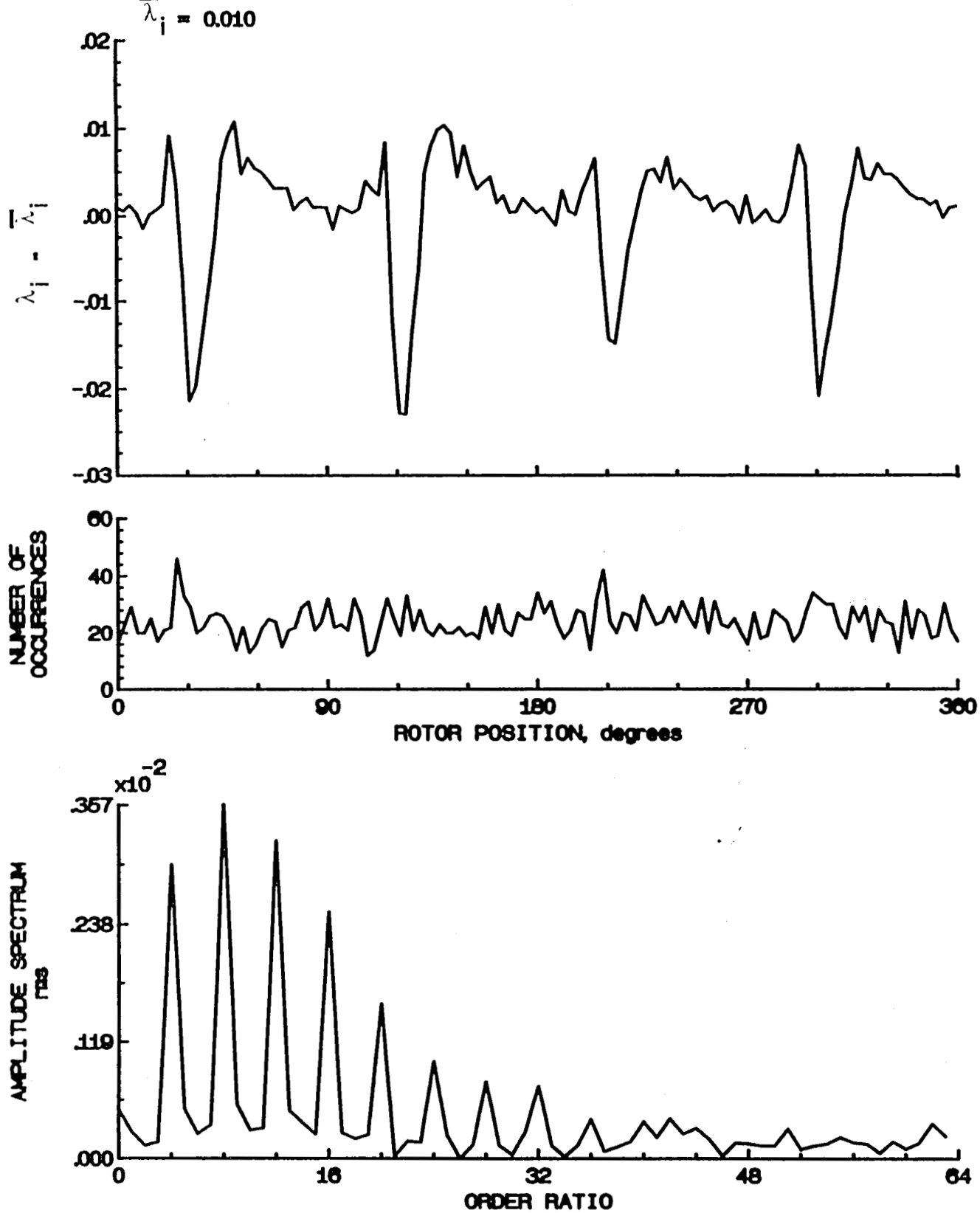


Figure 128.- Induced inflow velocity measured at 210 degrees and r/R of 0.94.



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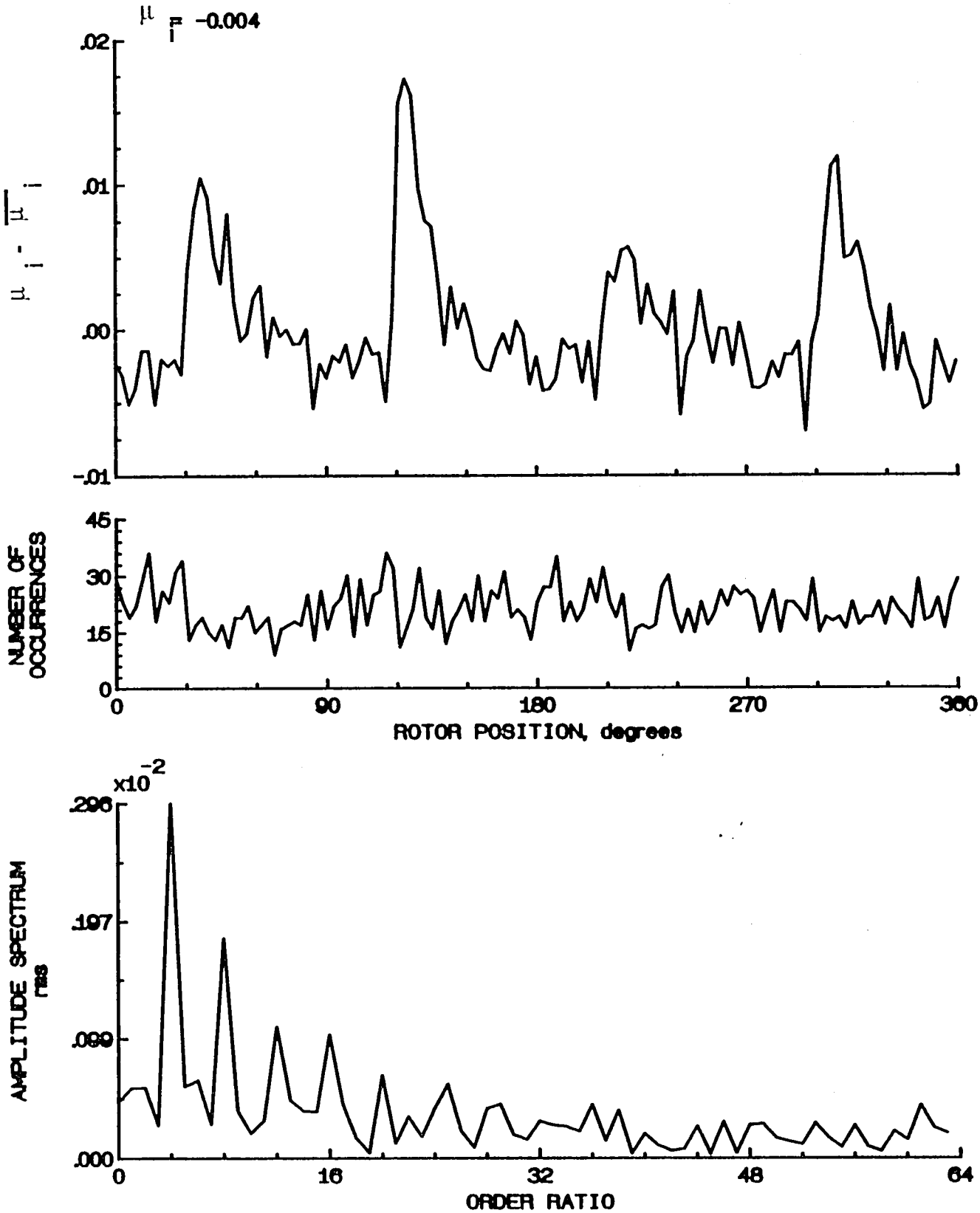
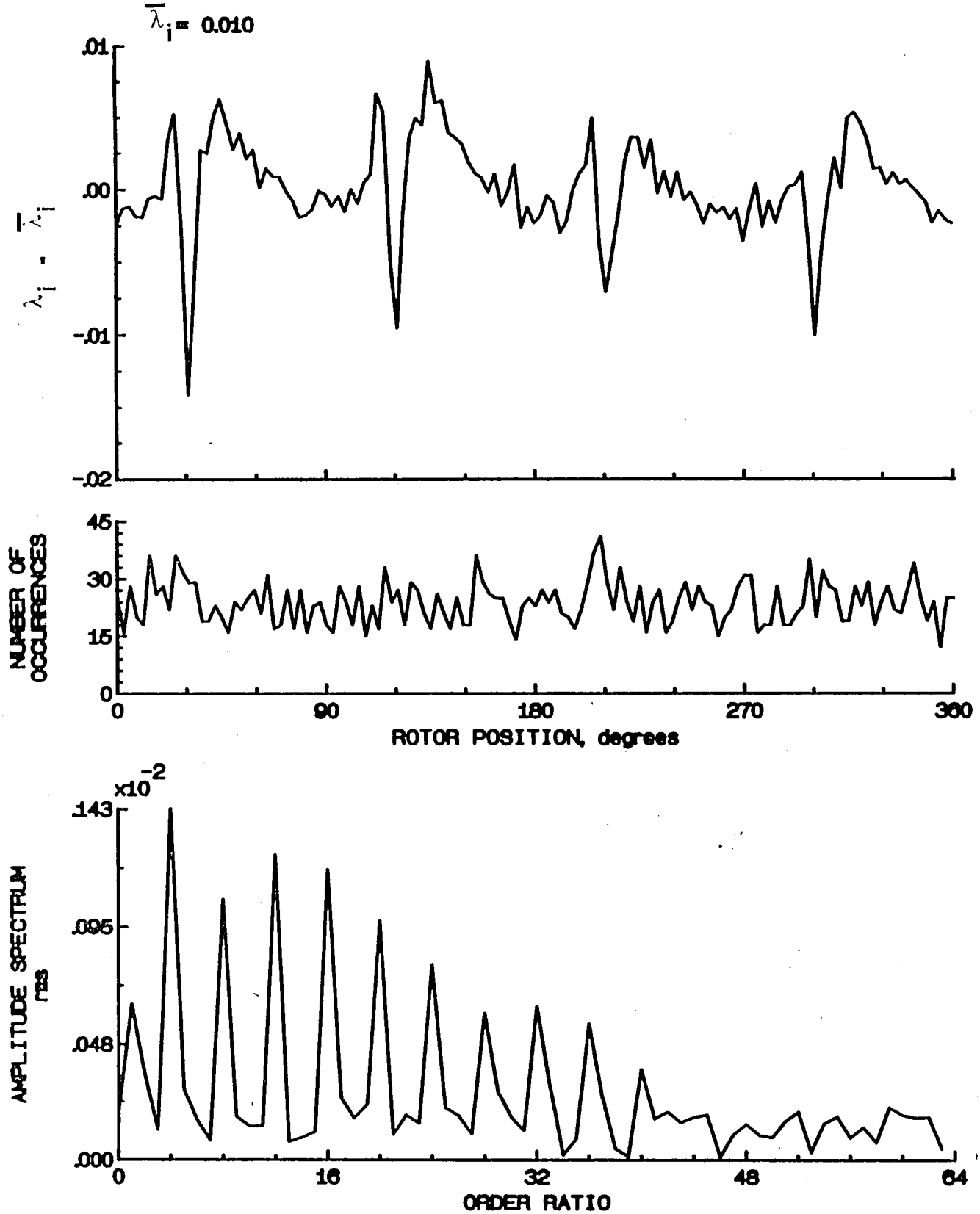


Figure 129.- Induced inflow velocity measured at 210 degrees and r/R of 0.98.



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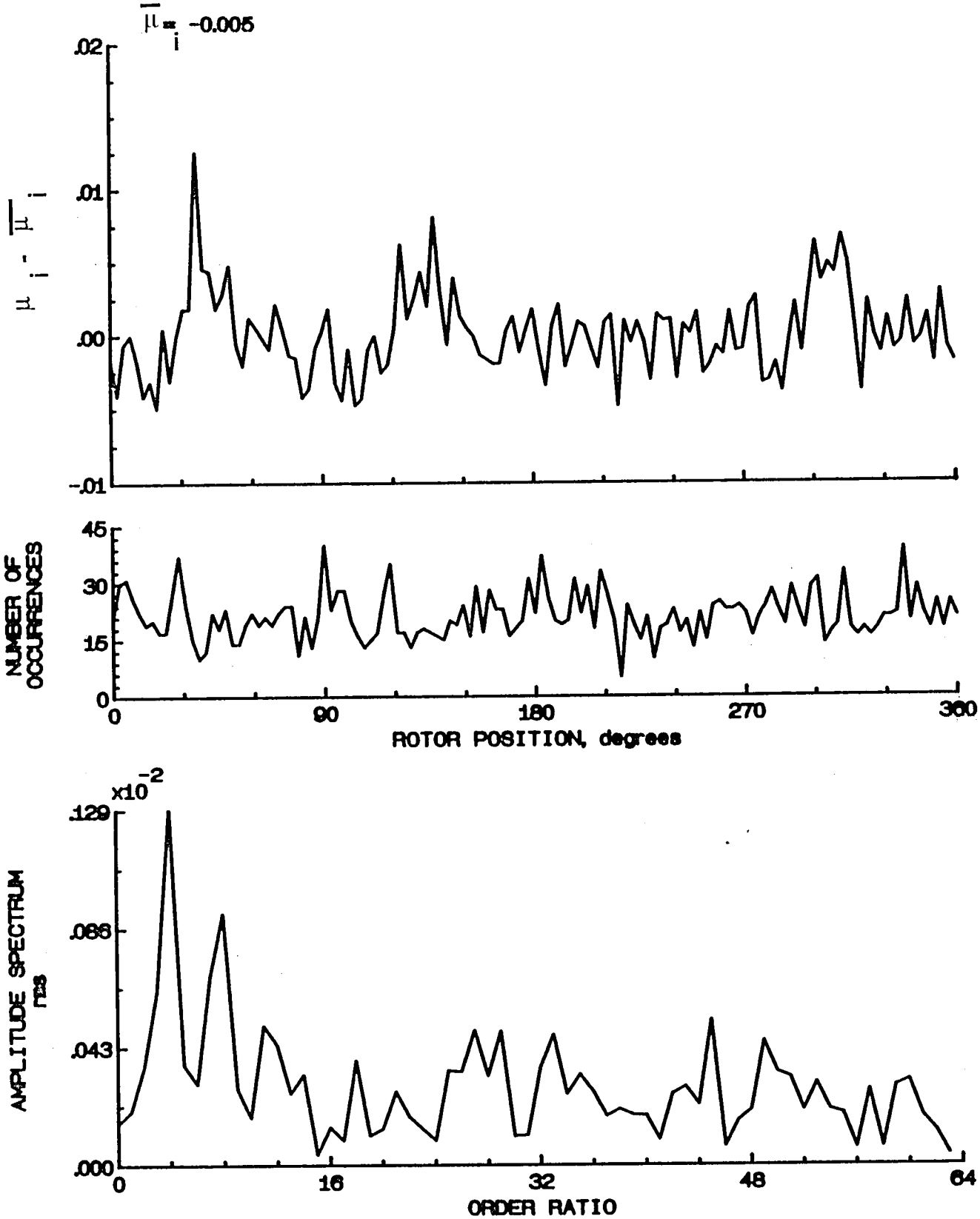
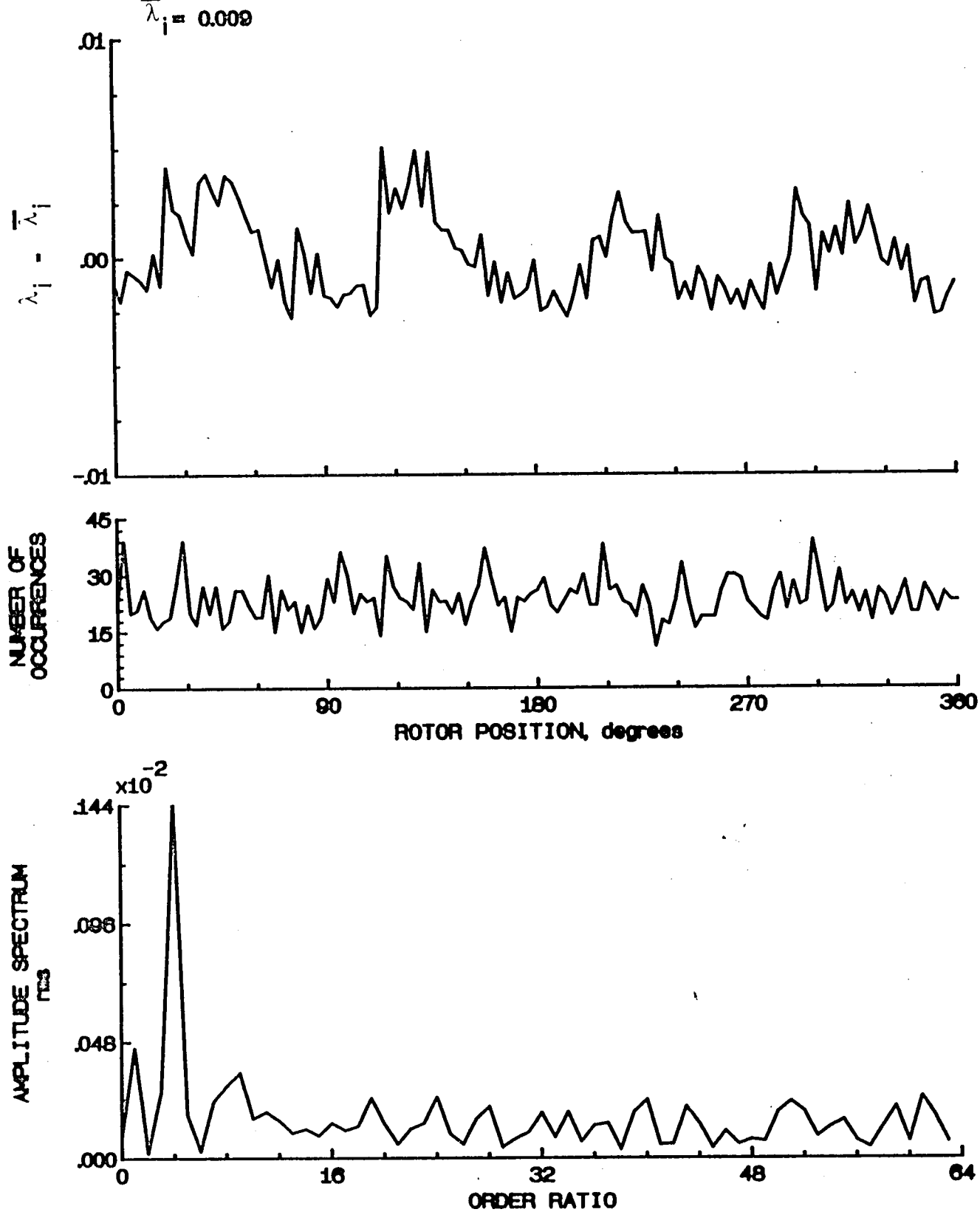


Figure 130.- Induced inflow velocity measured at 210 degrees and r/R of 1.02.



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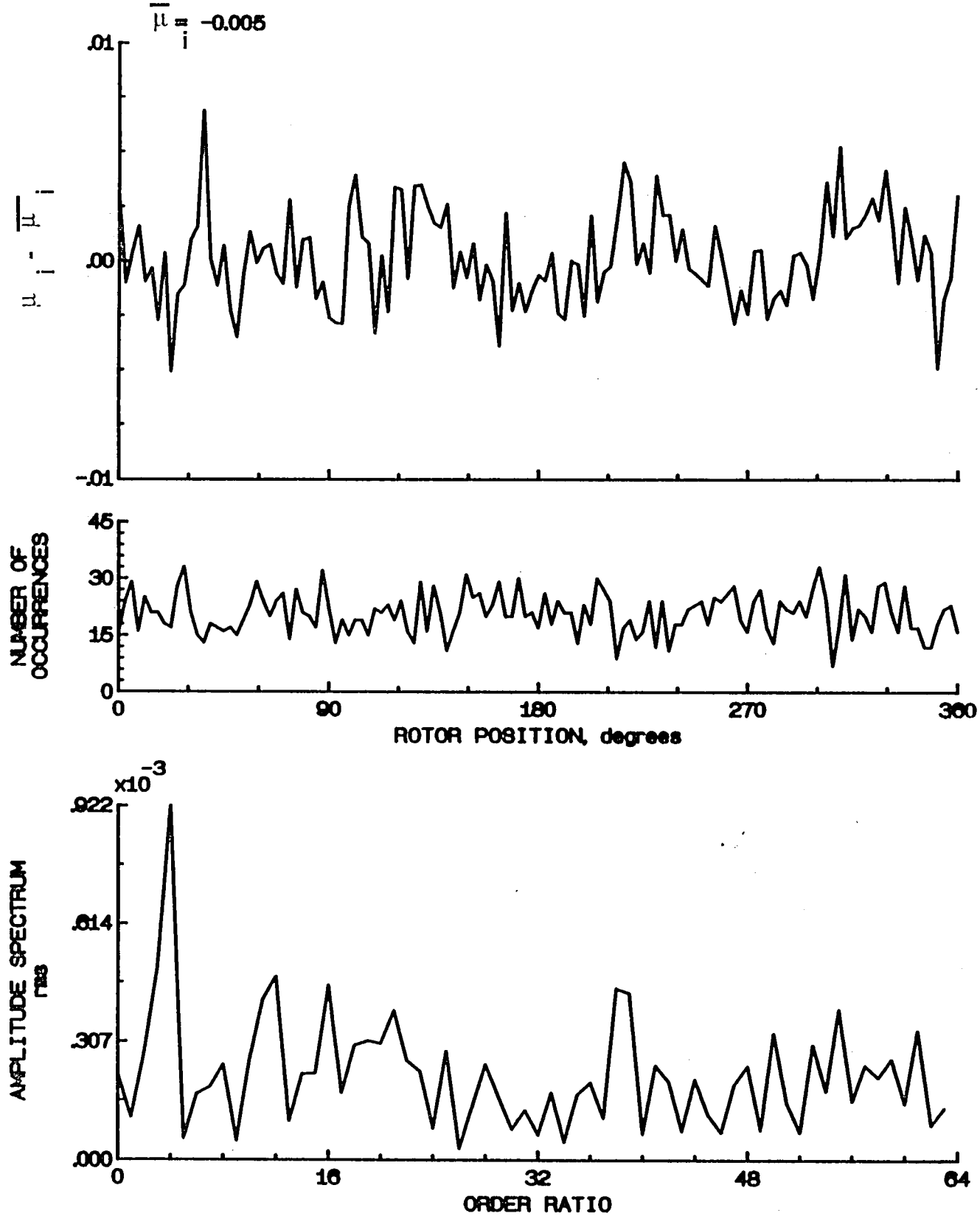
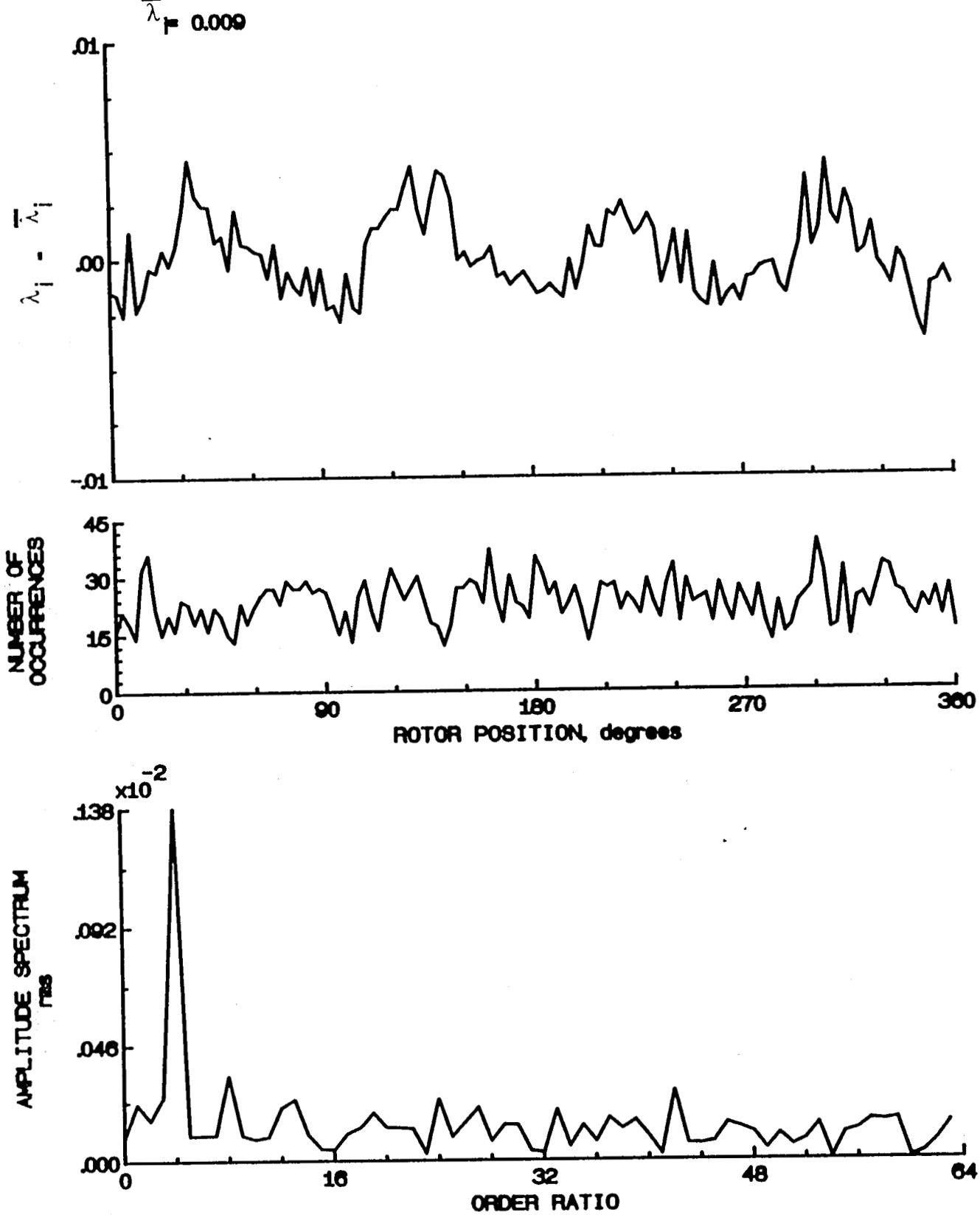


Figure 131.- Induced inflow velocity measured at 210 degrees and r/R of 1.04.



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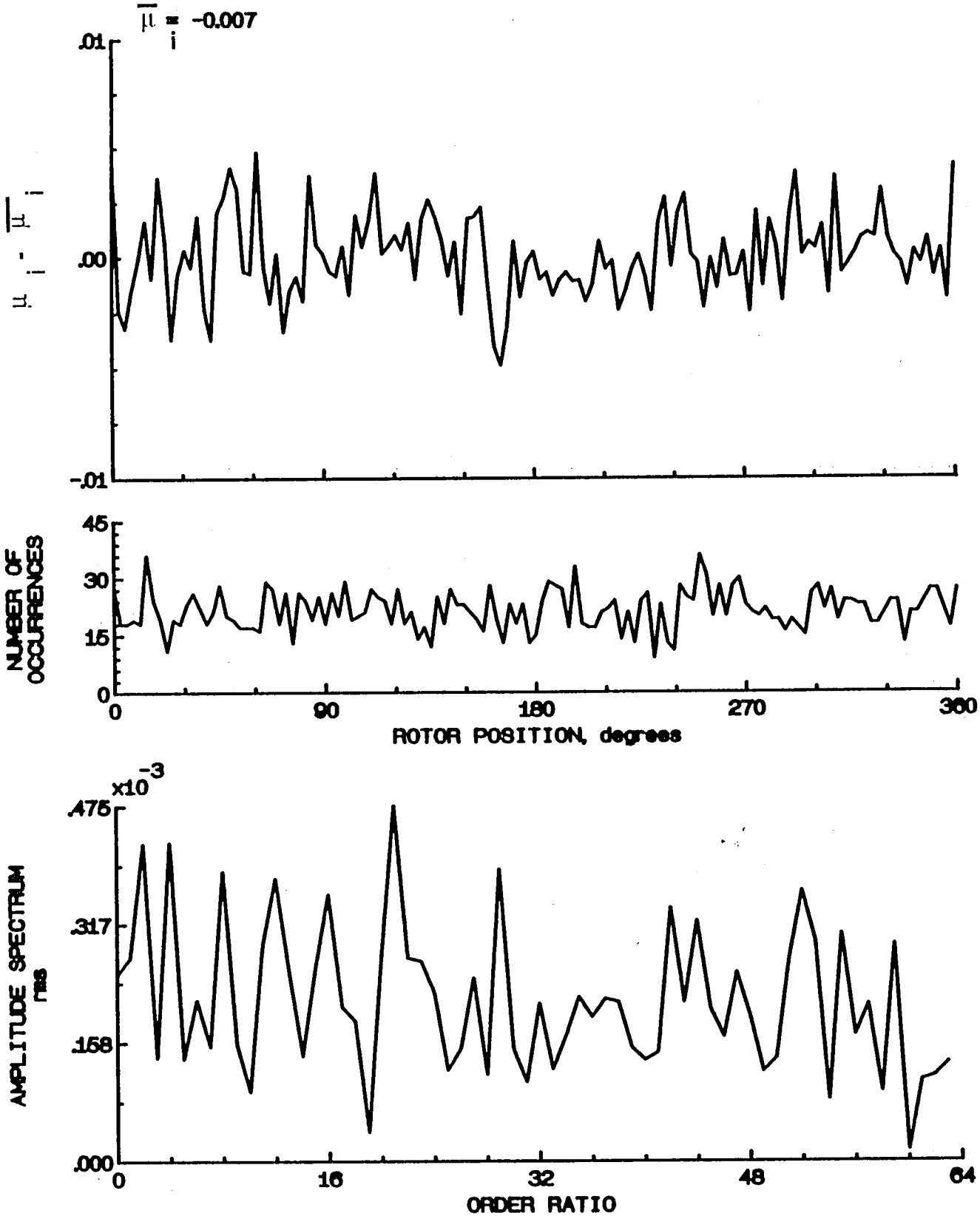


Figure 132.- Induced inflow velocity measured at 210 degrees and r/R of 1.10.

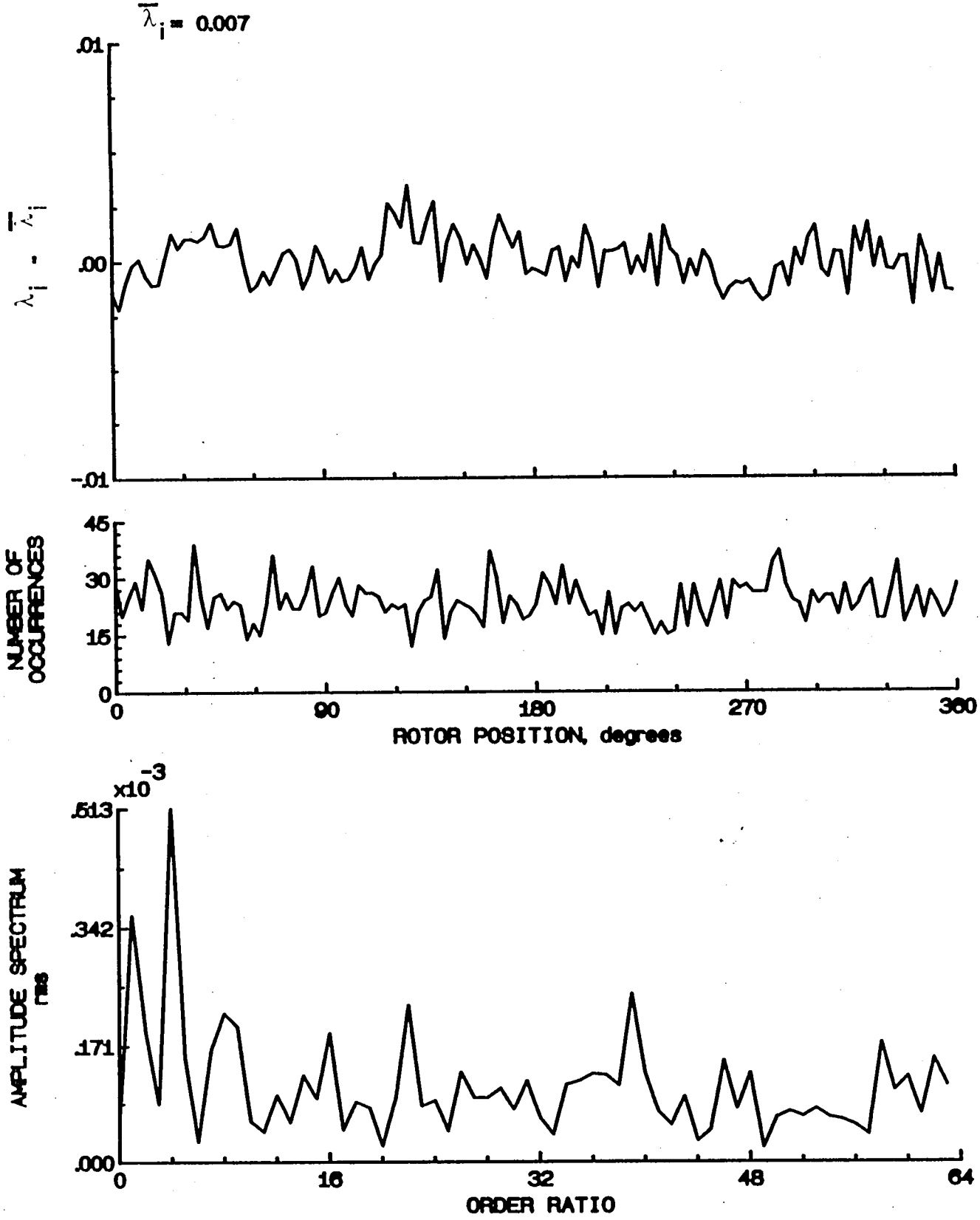


Figure 132.- Concluded.

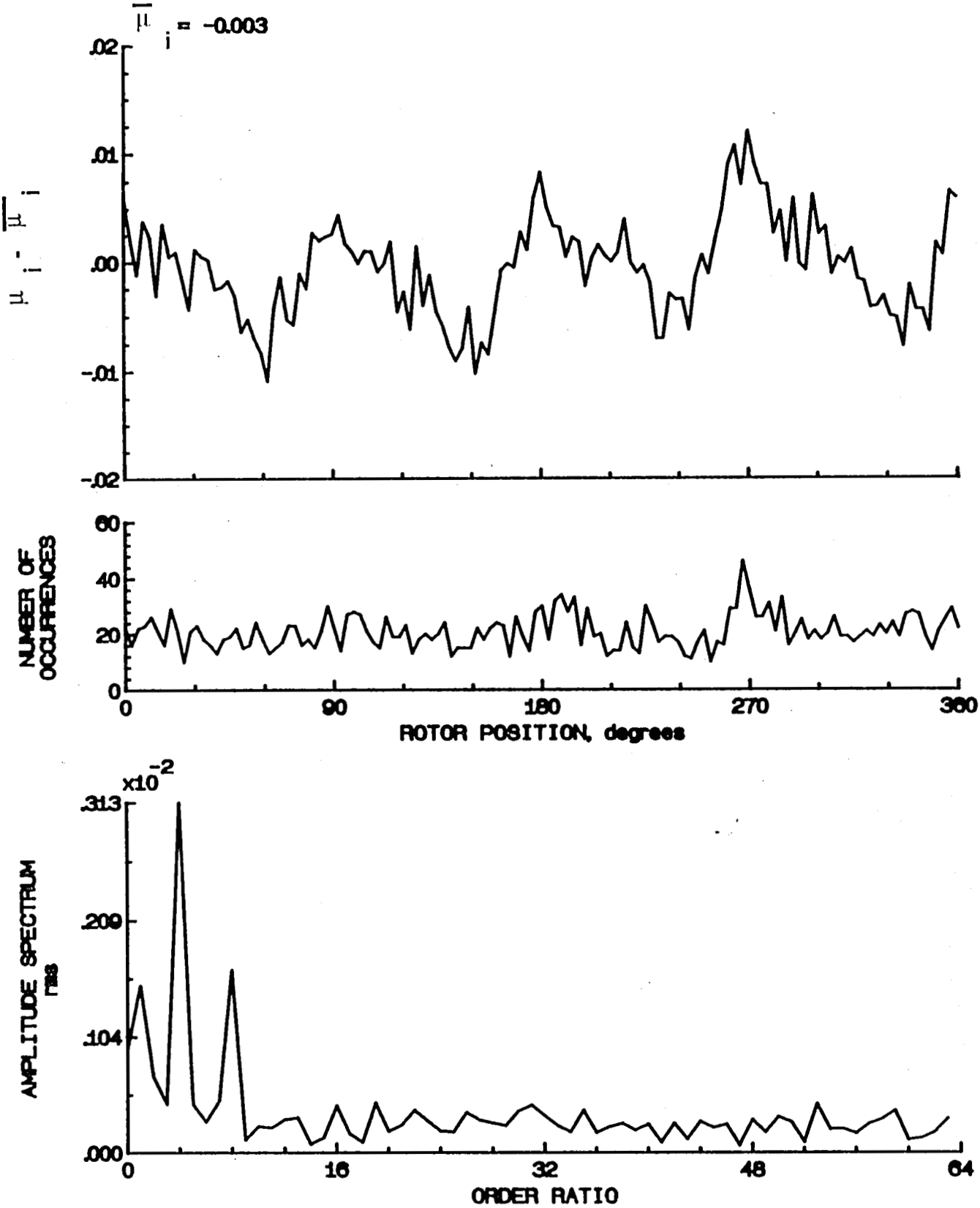


Figure 133.- Induced inflow velocity measured at 240 degrees and r/R of 0.20.

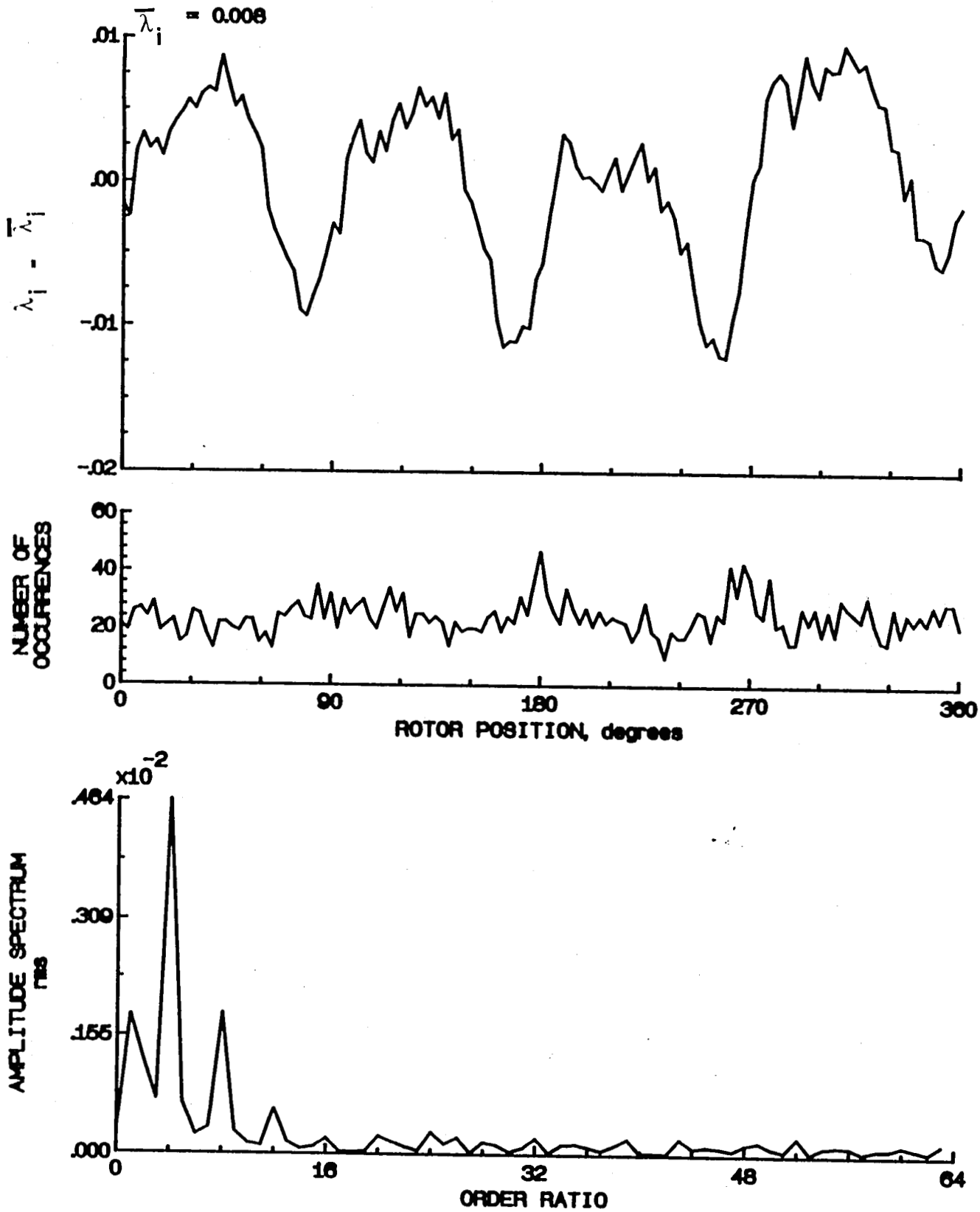


Figure 133.- Concluded.

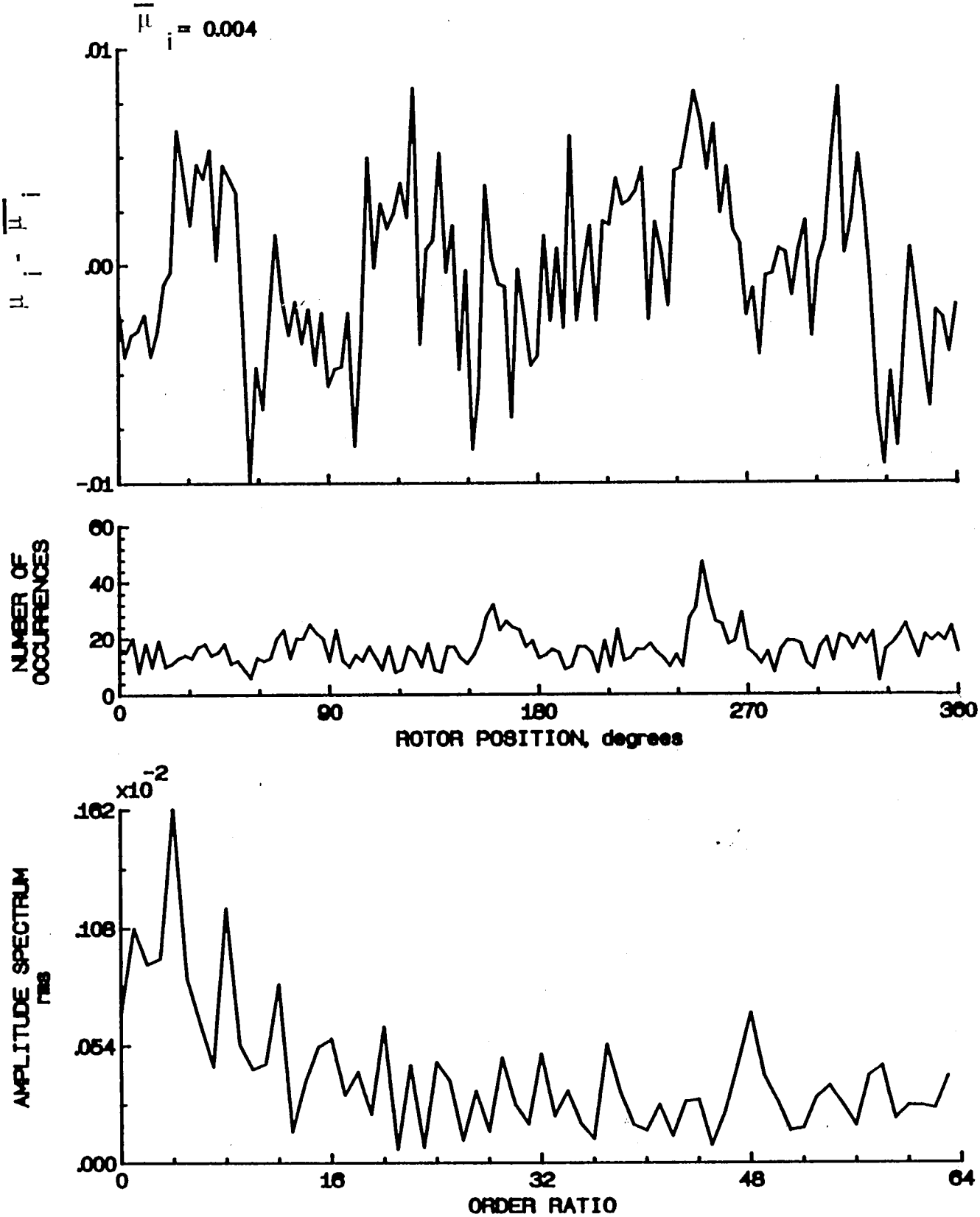


Figure 134.- Induced inflow velocity measured at 240 degrees and r/R of 0.40.

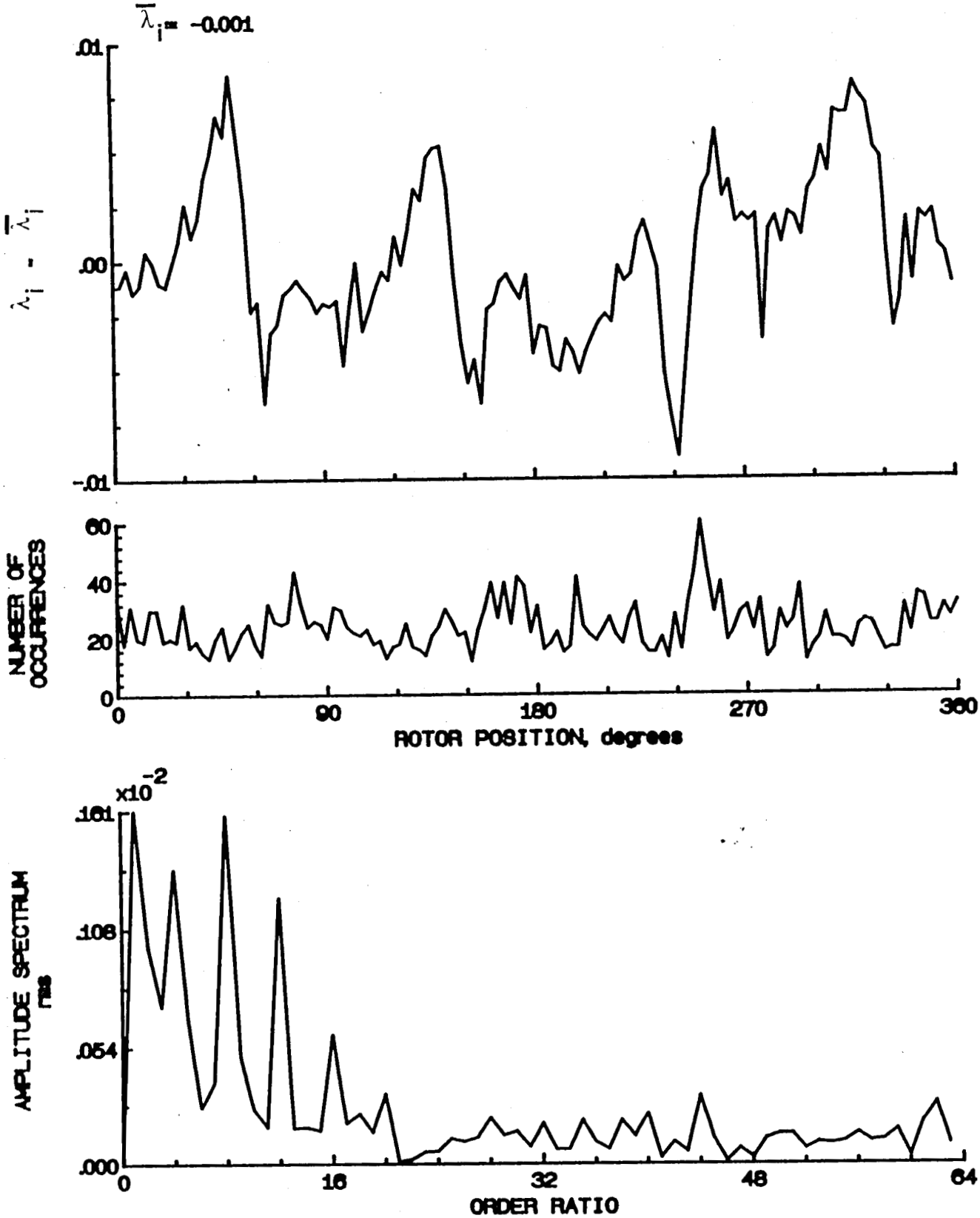


Figure 134.- Concluded.

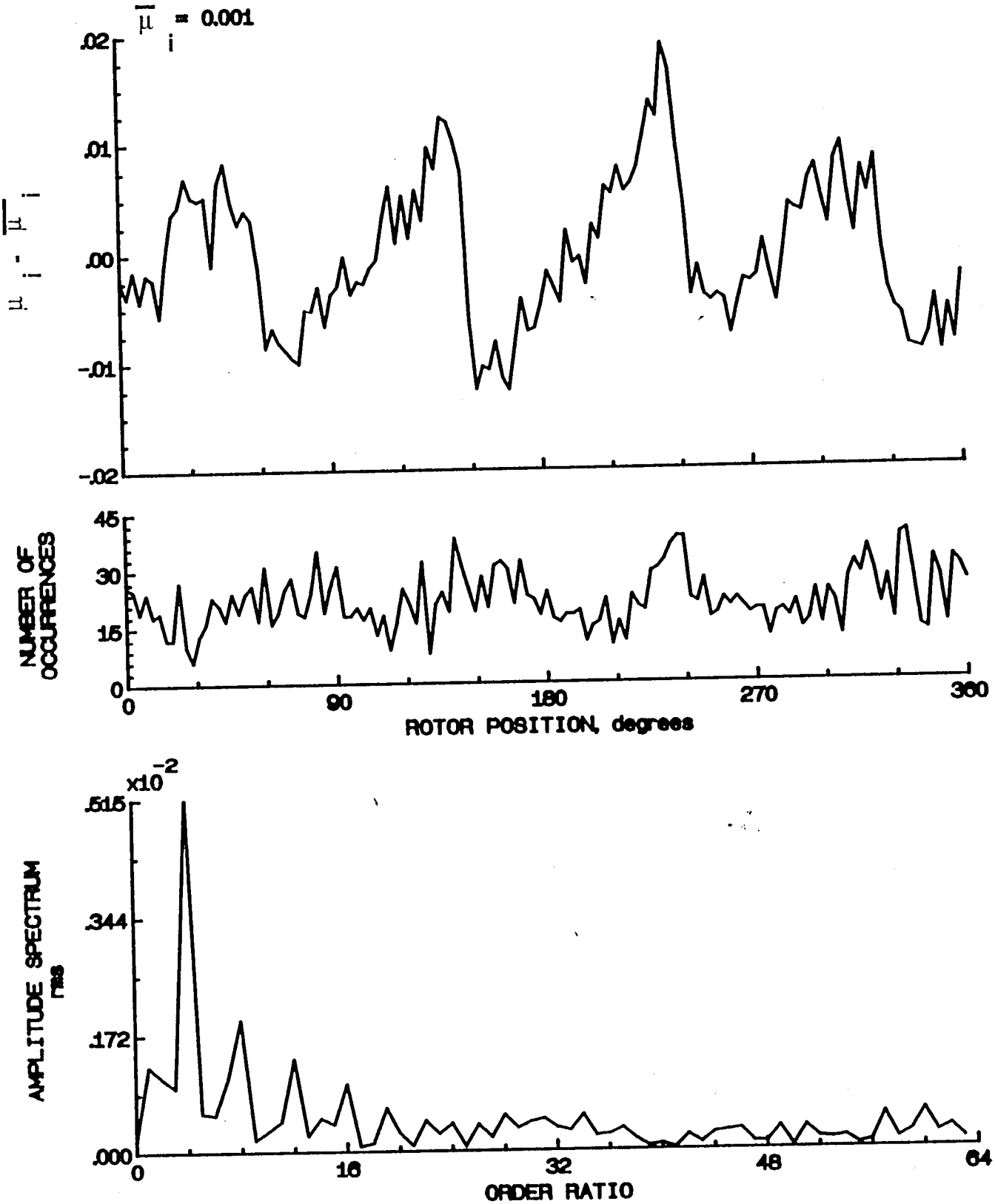
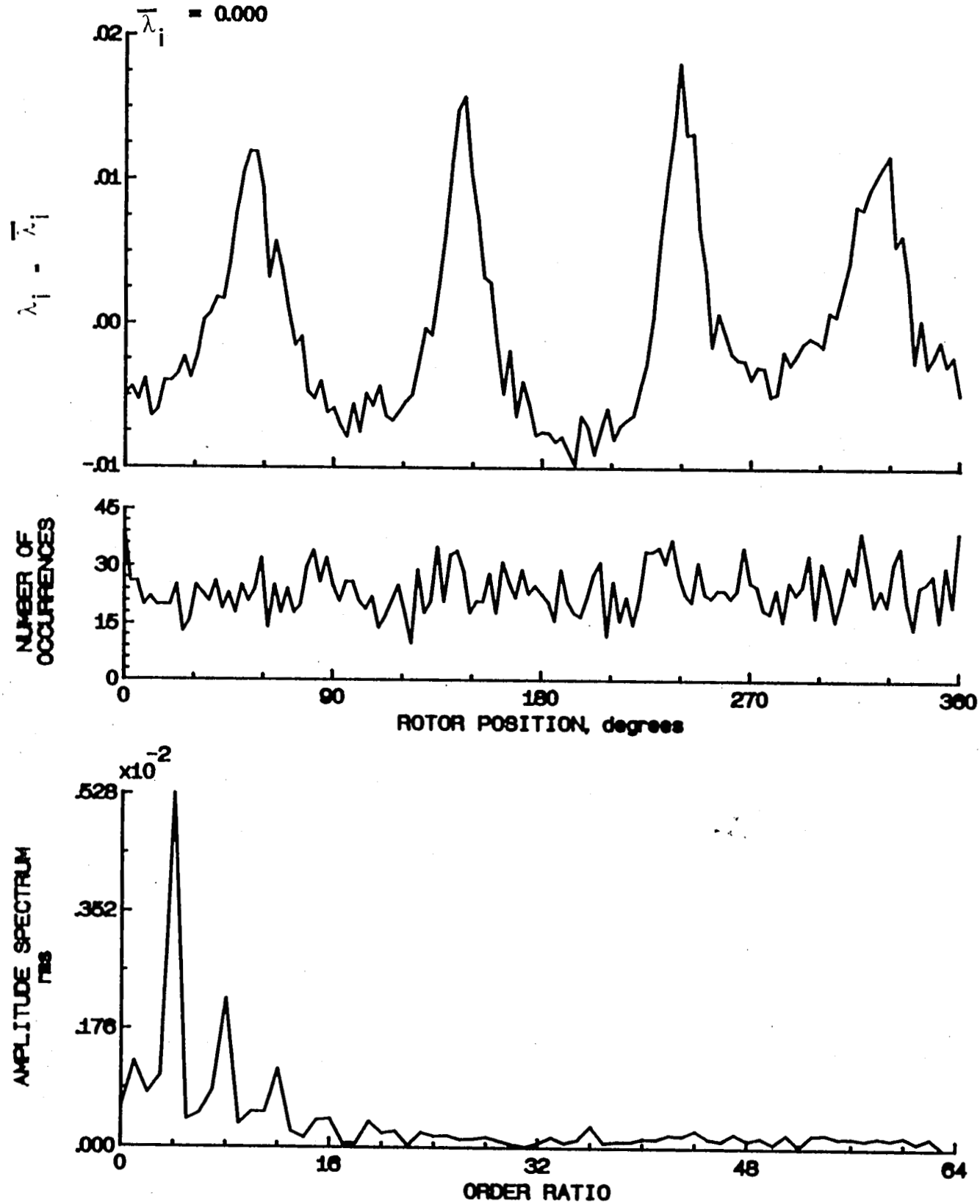


Figure 135.- Induced inflow velocity measured at 240 degrees and r/R of 0.50.



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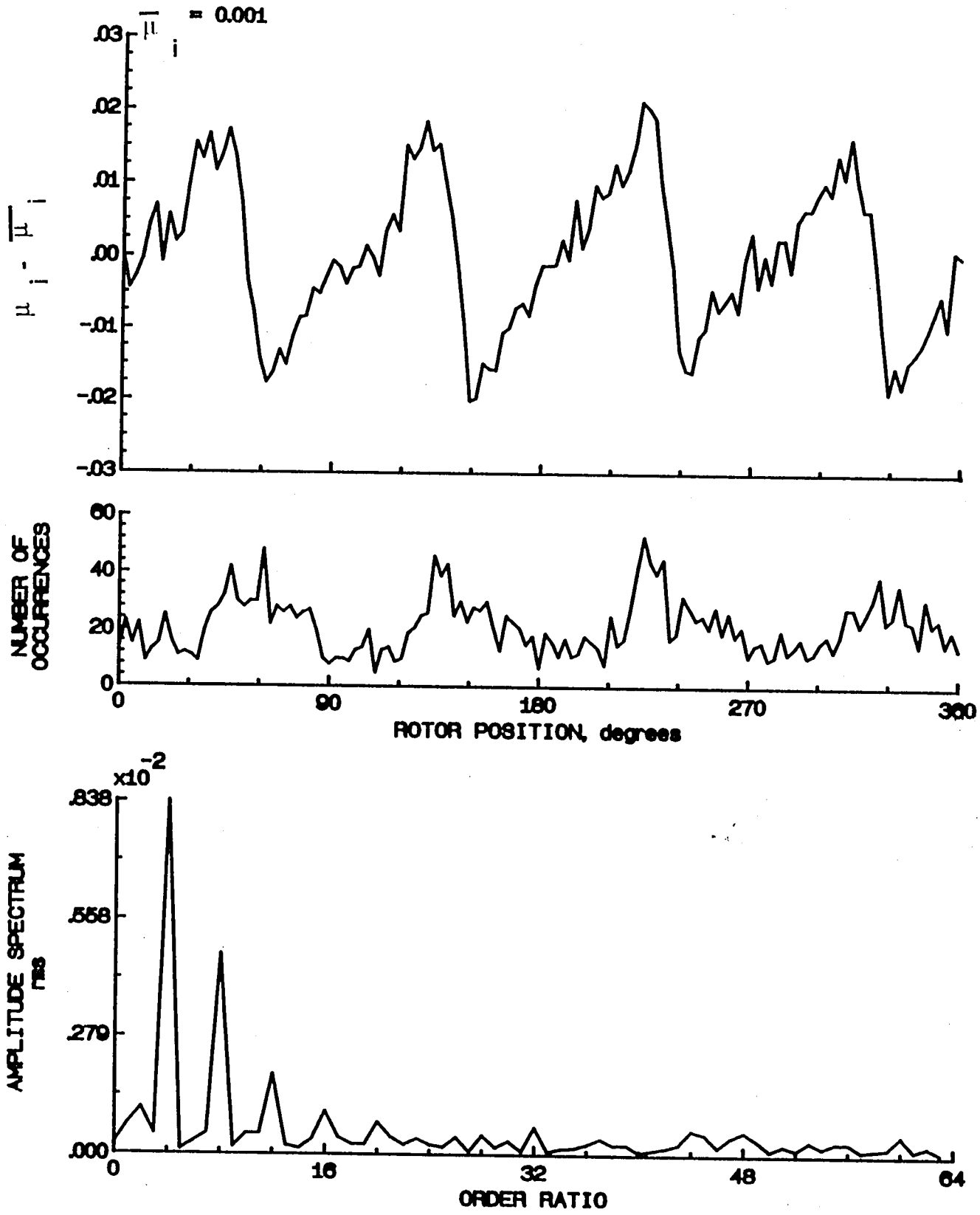


Figure 136.- Induced inflow velocity measured at 240 degrees and r/R of 0.60.

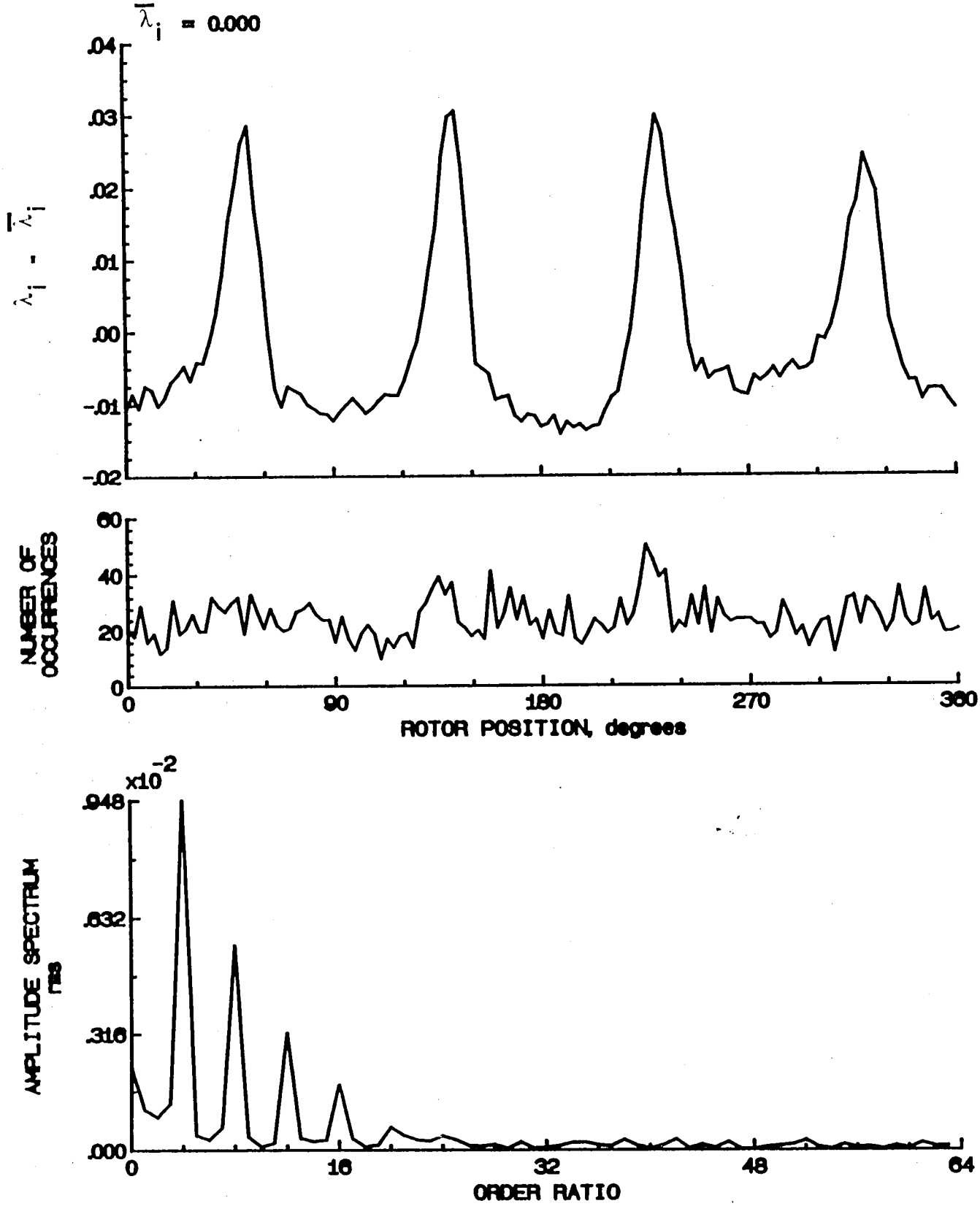


Figure 136.- Concluded.

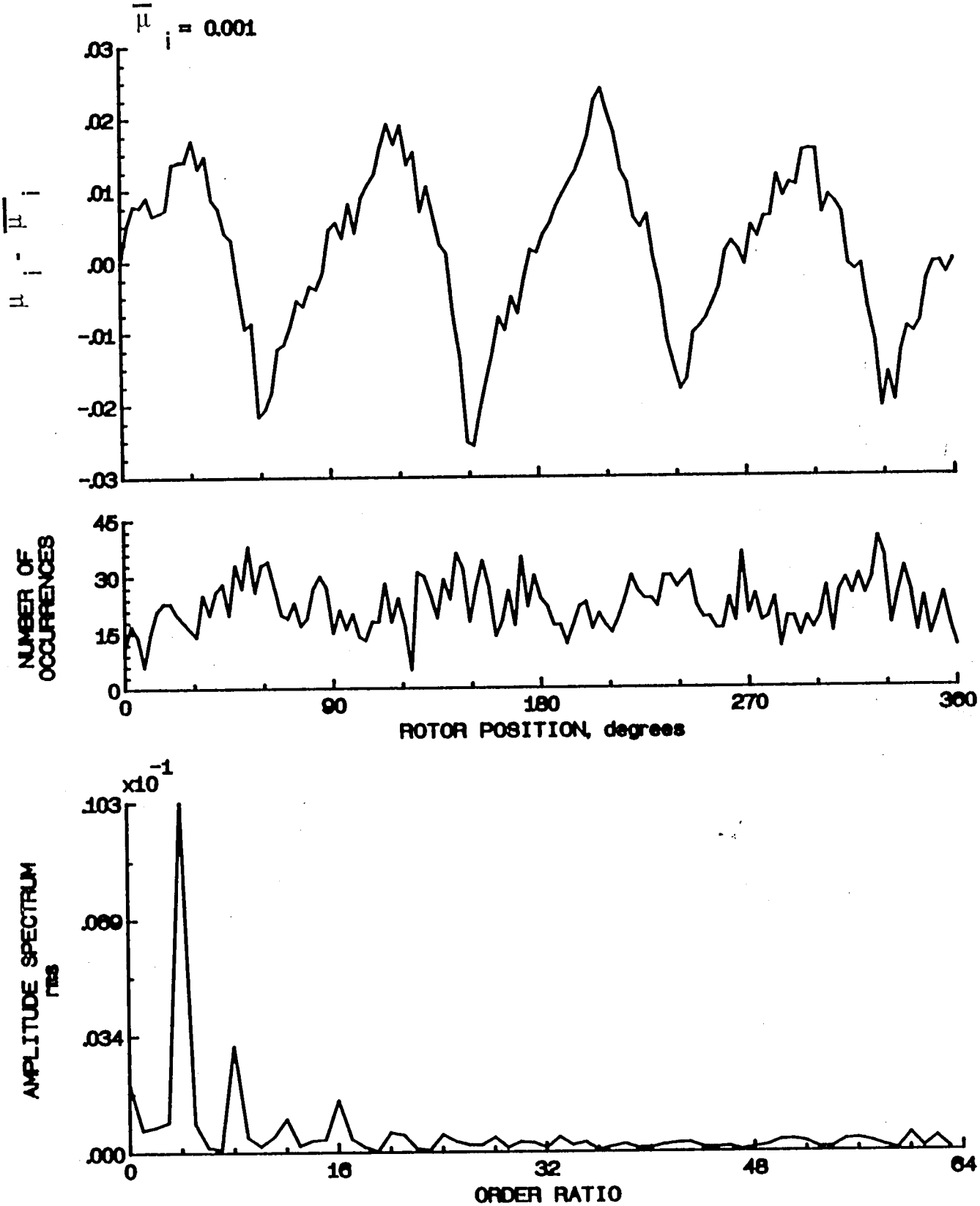


Figure 137.- Induced inflow velocity measured at 240 degrees and r/R of 0.70.

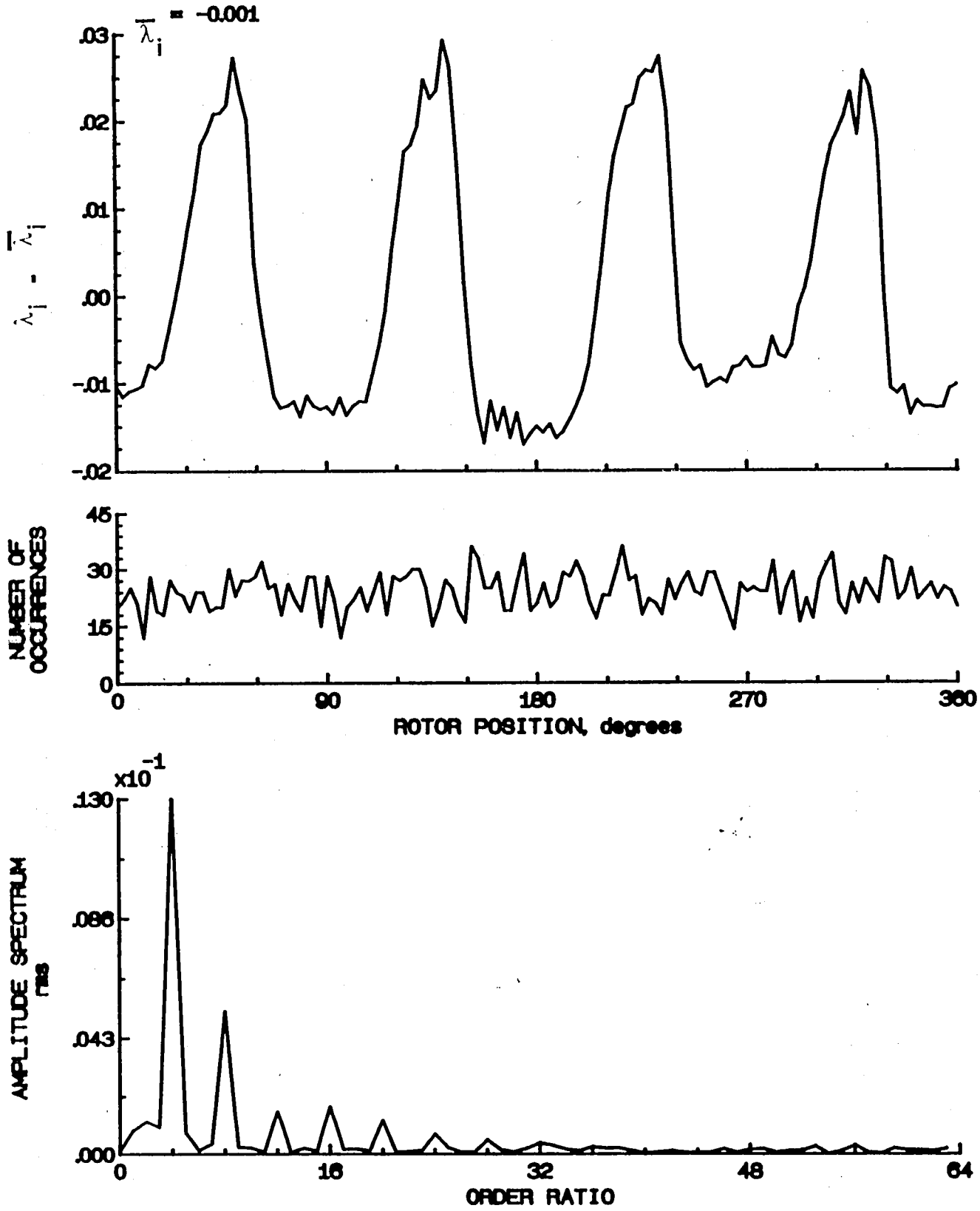


Figure 137.- Concluded.

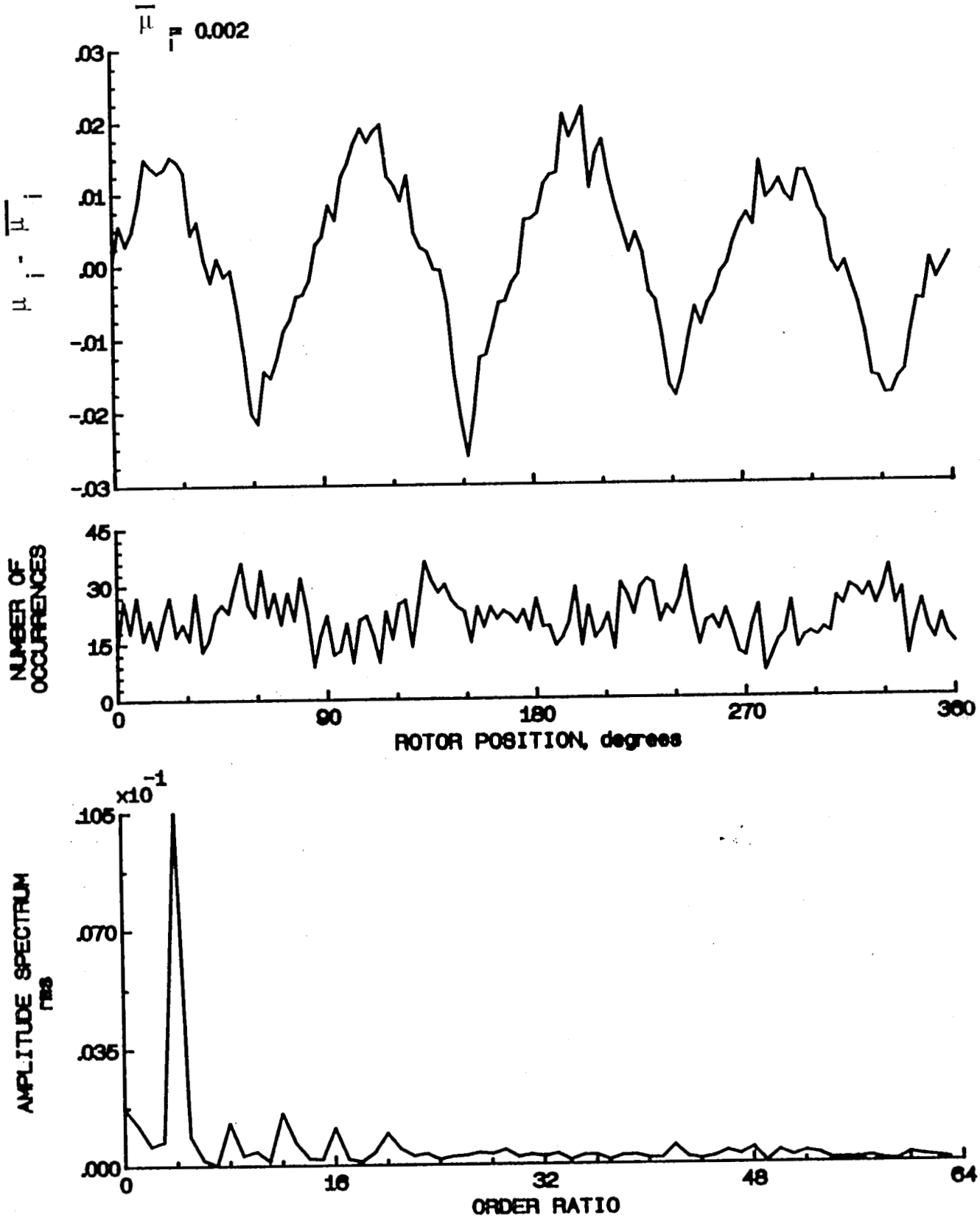
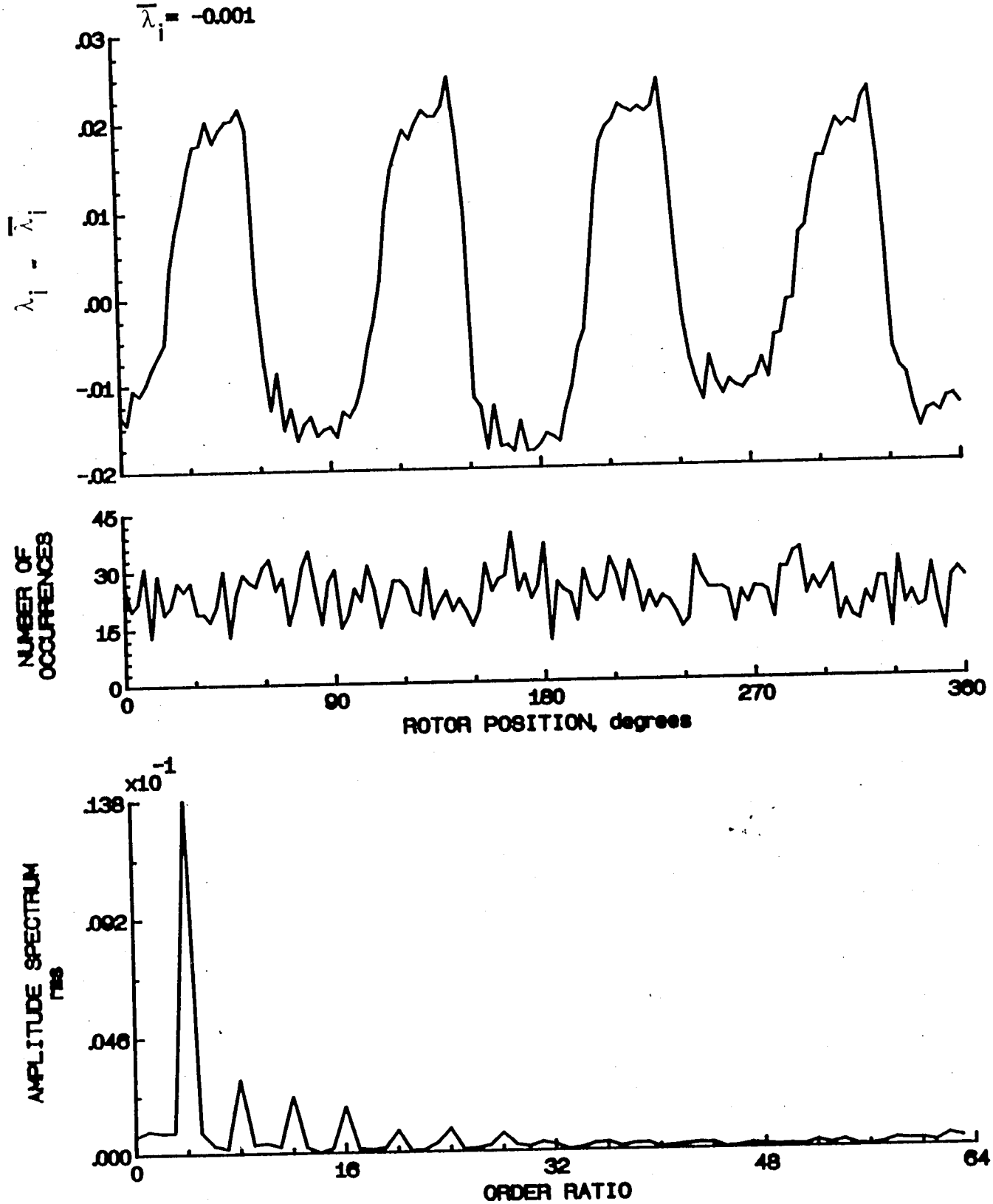


Figure 138.- Induced inflow velocity measured at 240 degrees and r/R of 0.74.



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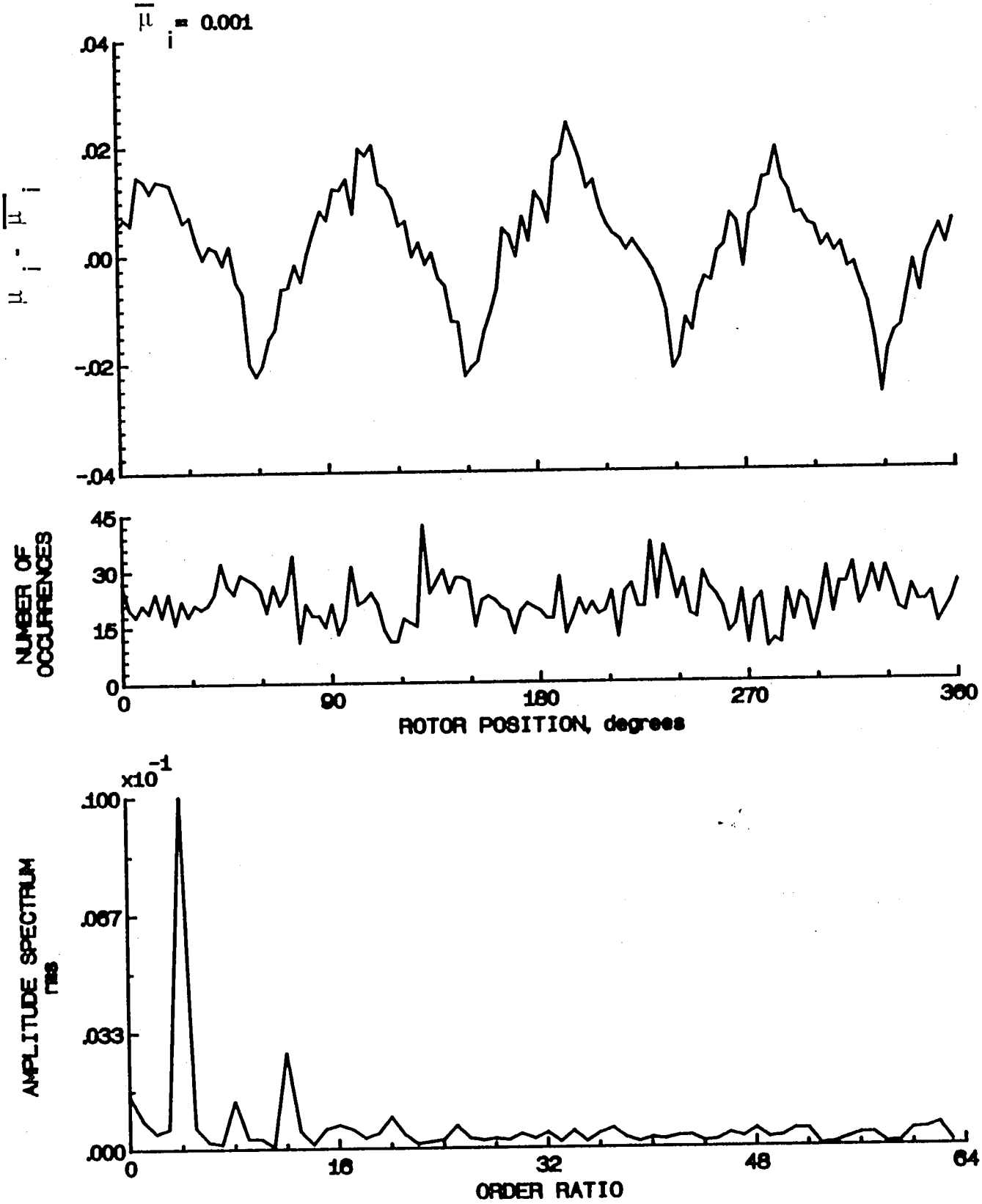


Figure 139.- Induced inflow velocity measured at 240 degrees and r/R of 0.78.

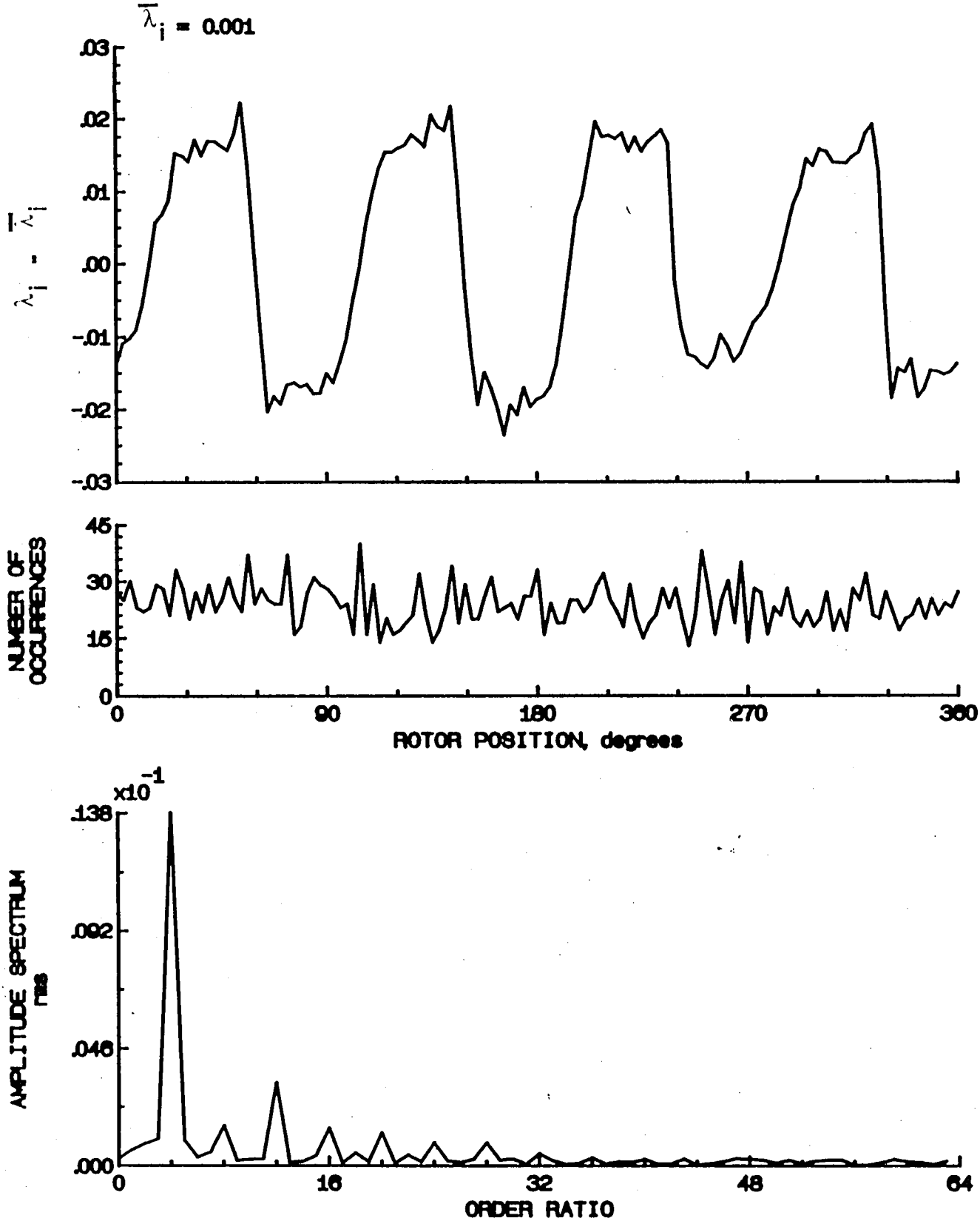


Figure 139.- Concluded.

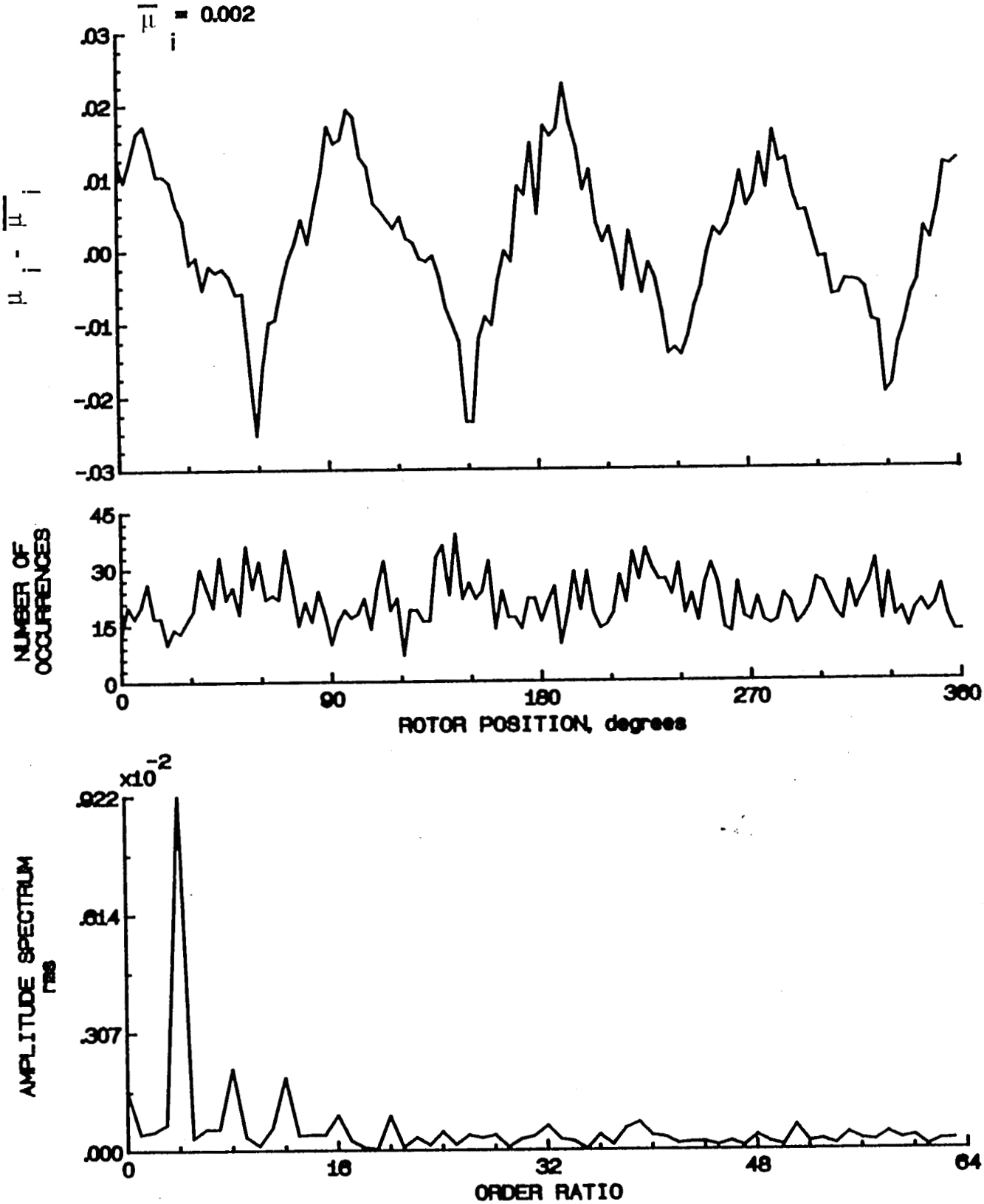
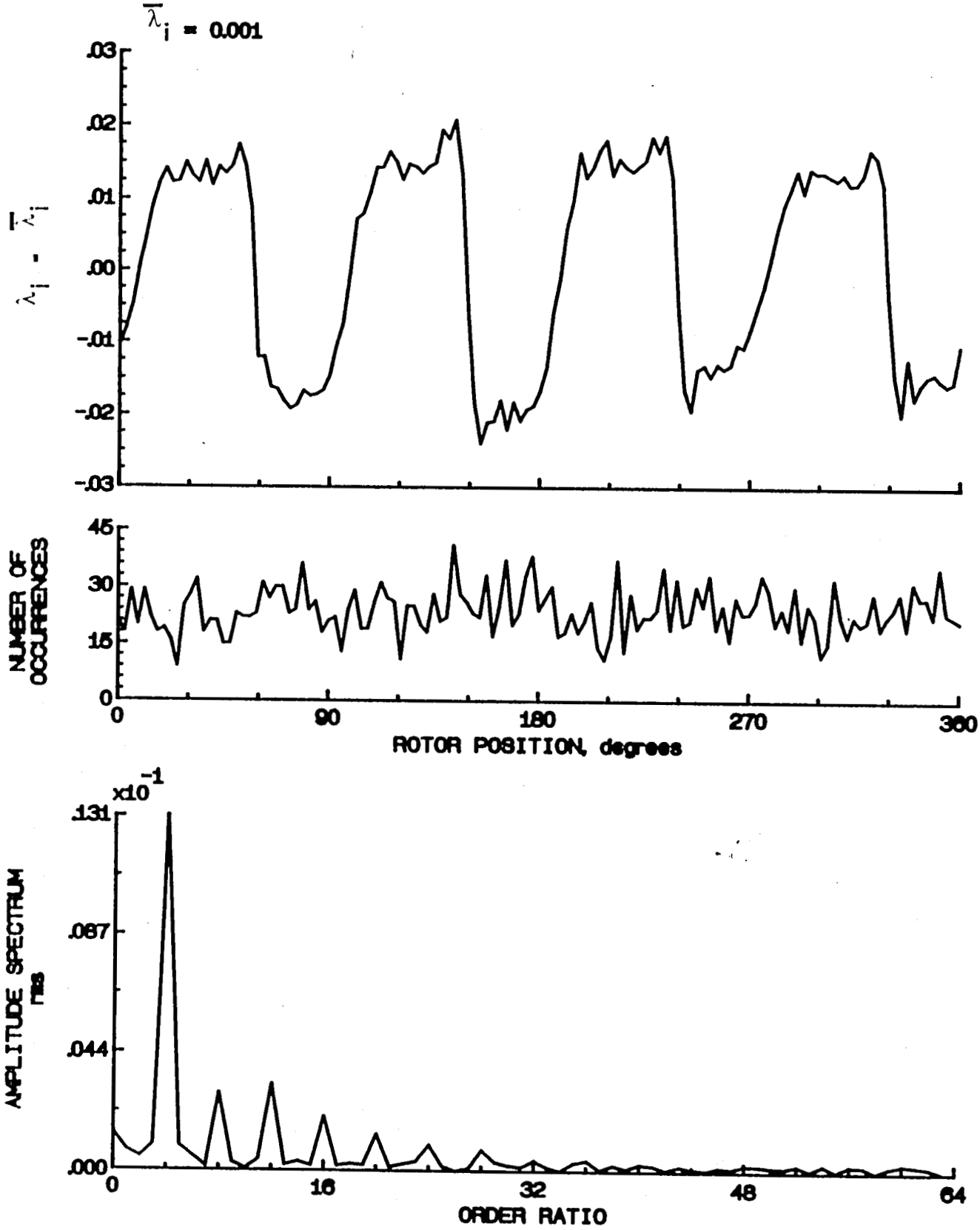


Figure 140.- Induced inflow velocity measured at 240 degrees and r/R of 0.82.



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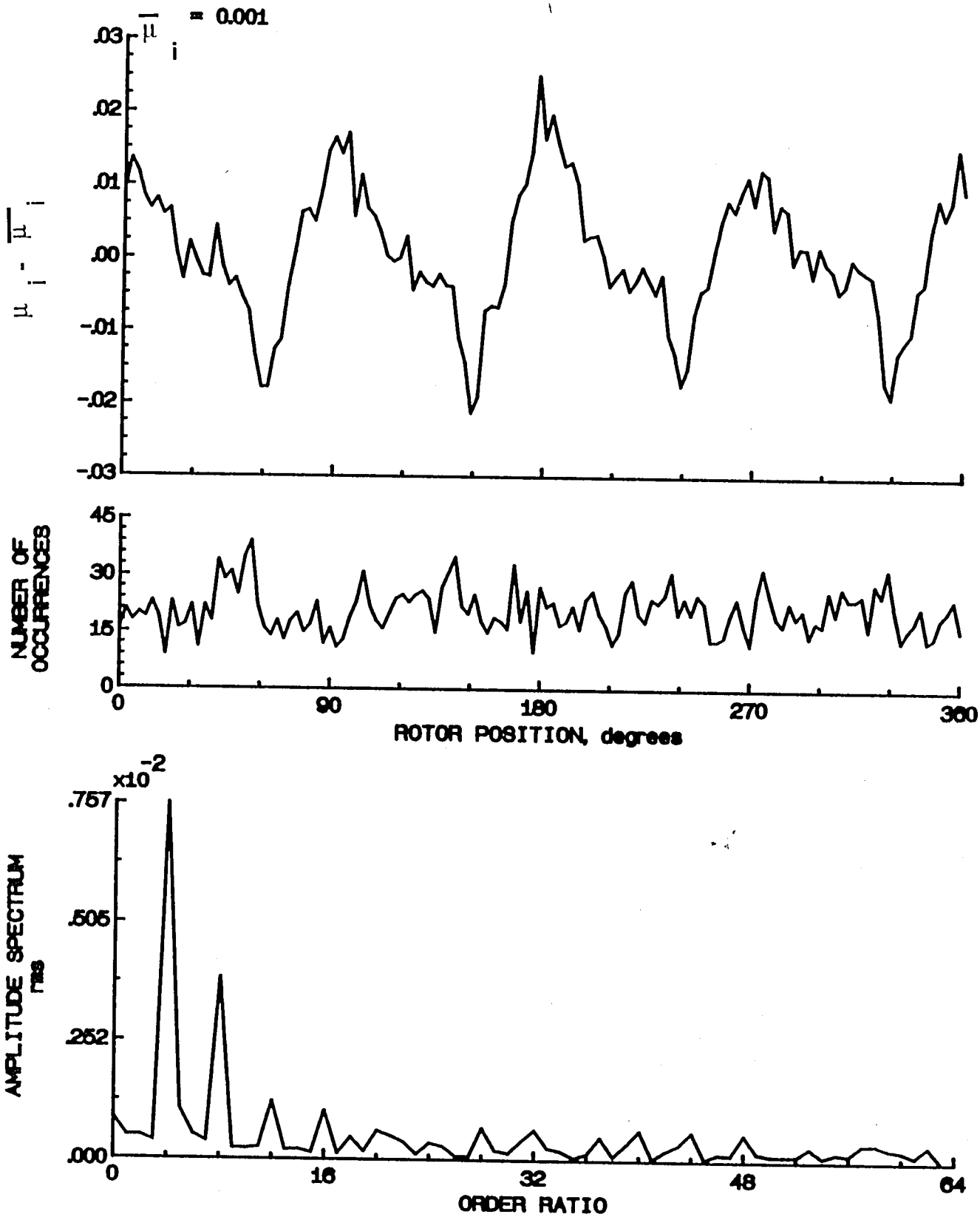


Figure 141.- Induced inflow velocity measured at 240 degrees and r/R of 0.86.

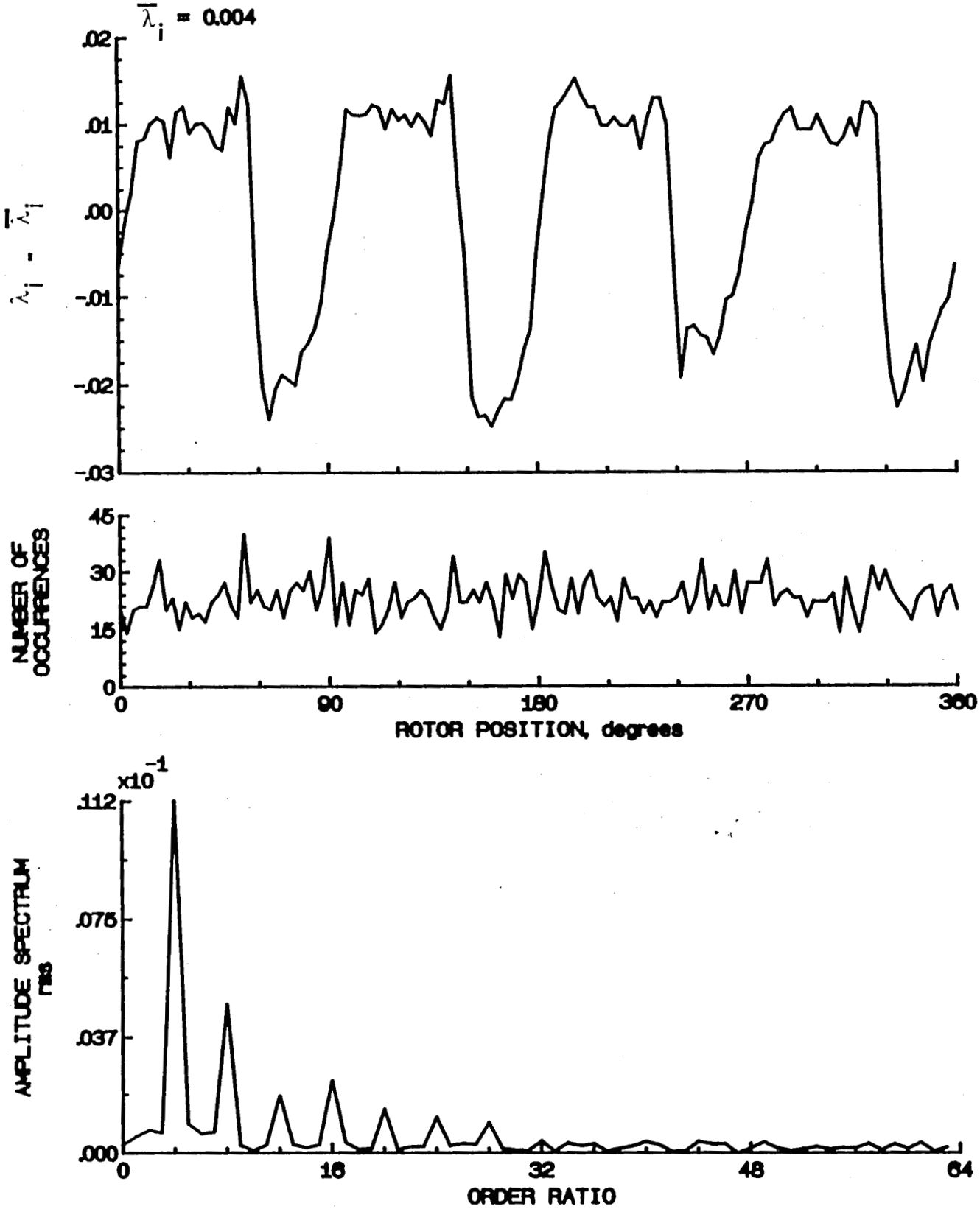


Figure 141.- Concluded.

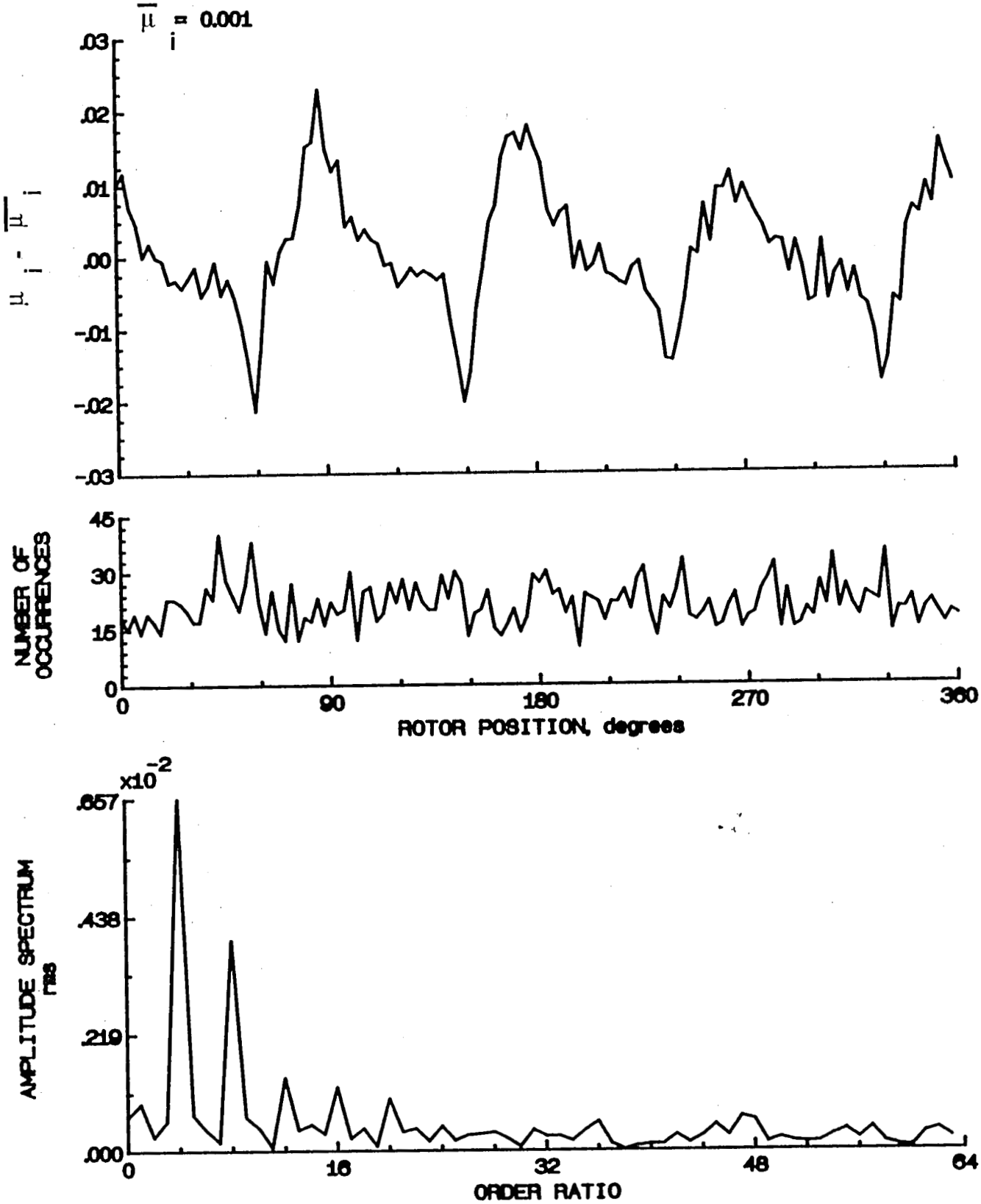


Figure 142.- Induced inflow velocity measured at 240 degrees and r/R of 0.90.

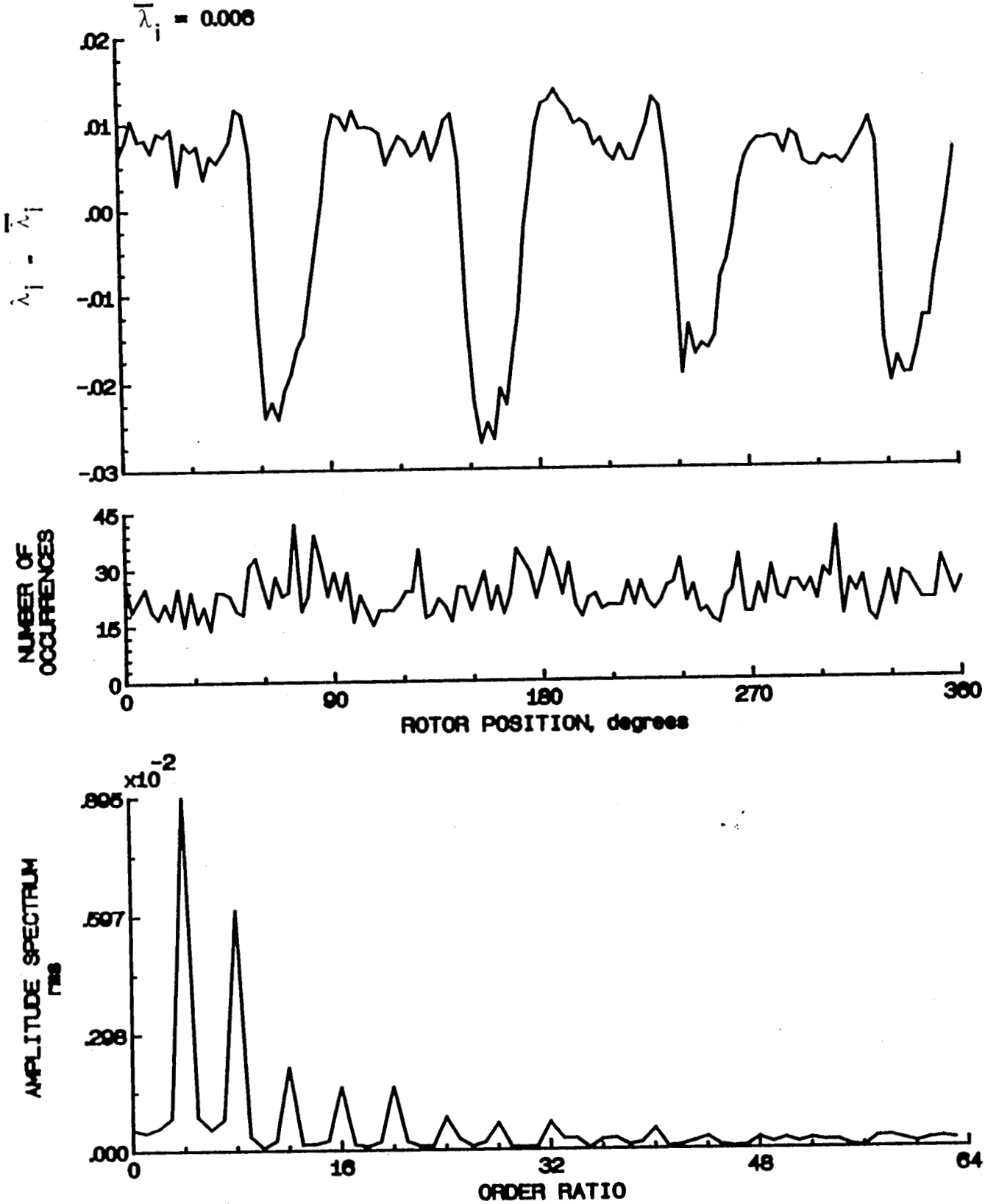


Figure 142.- Concluded.

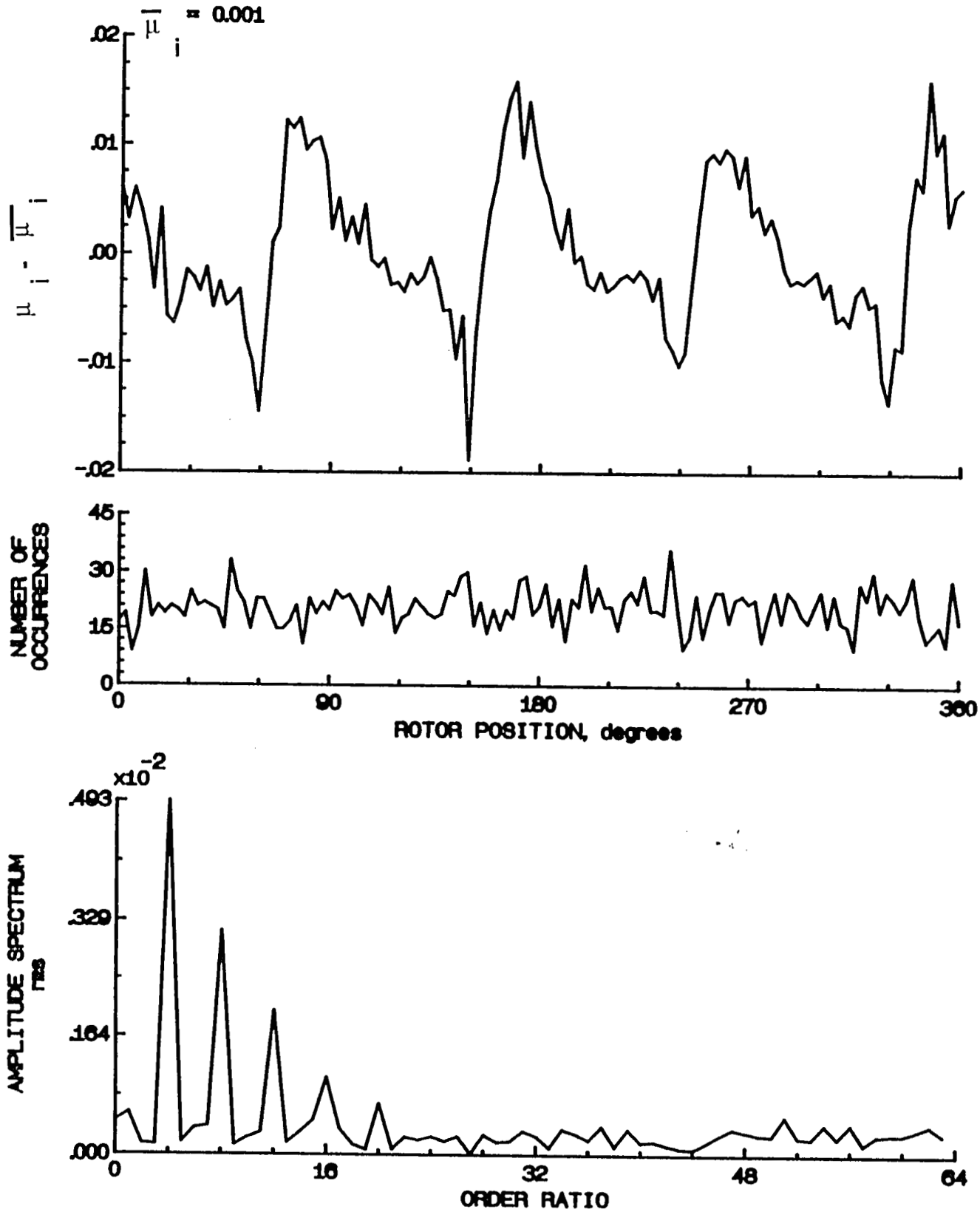
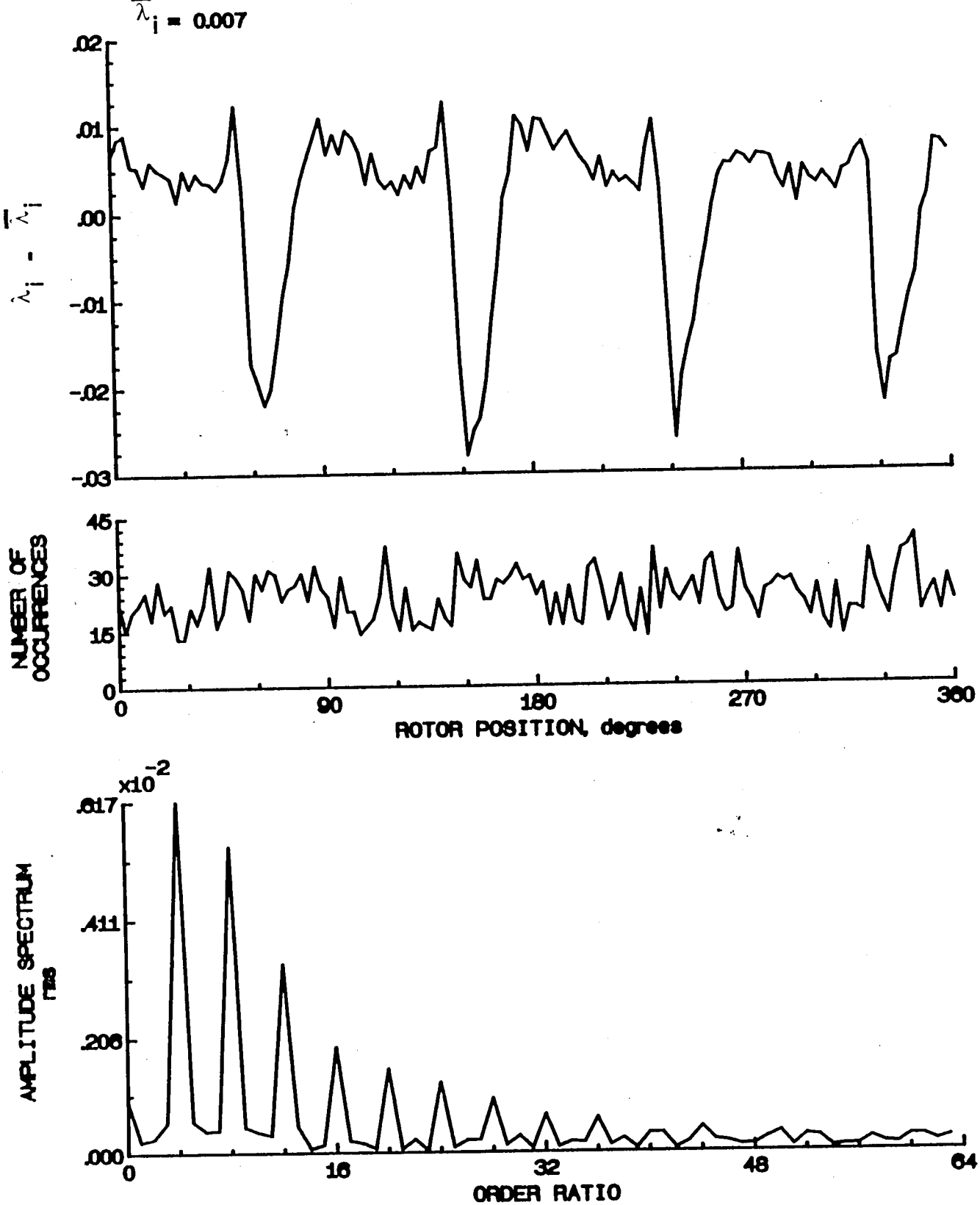


Figure 143.- Induced inflow velocity measured at 240 degrees and r/R of 0.94.



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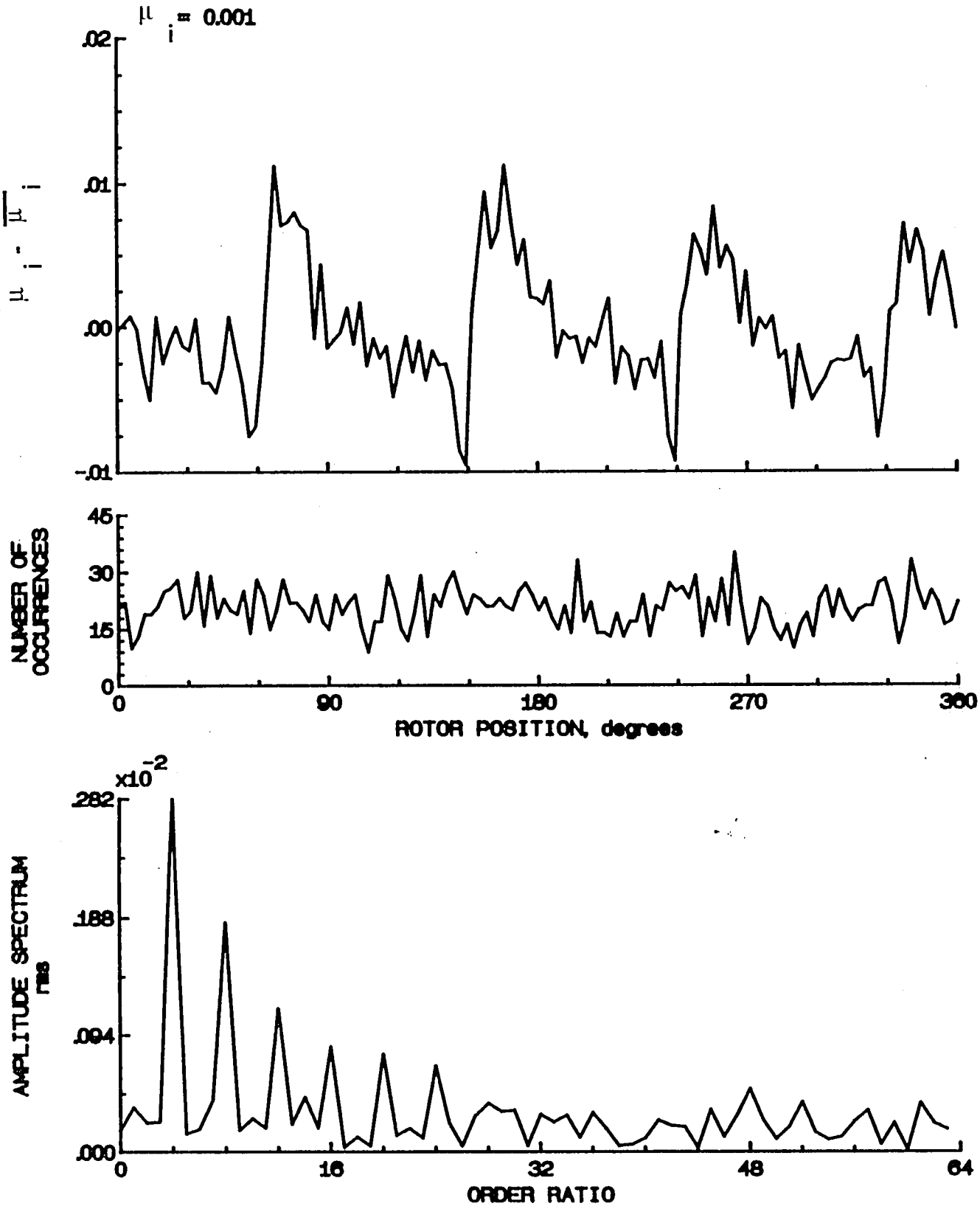
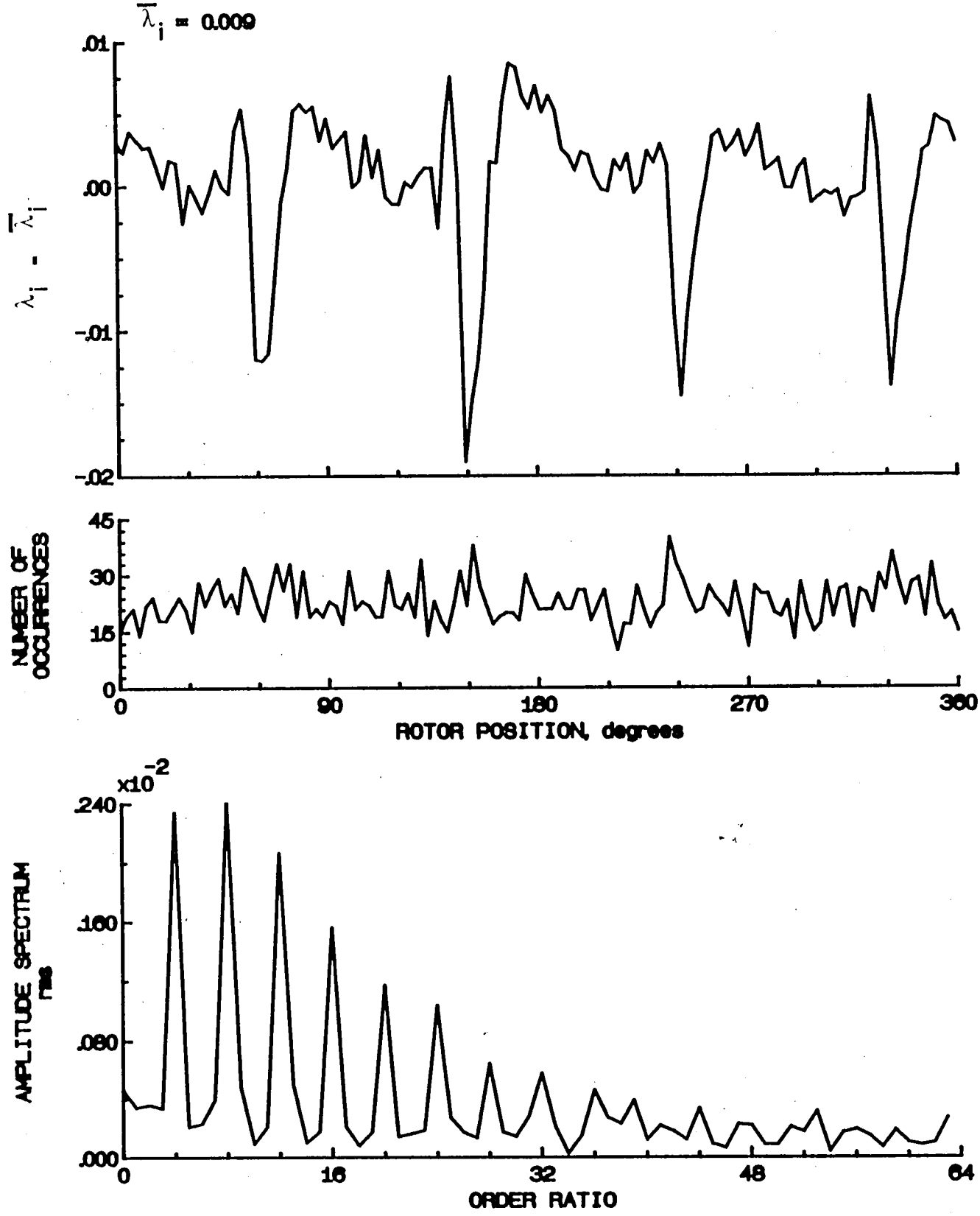


Figure 144.- Induced inflow velocity measured at 240 degrees and r/R of 0.98.



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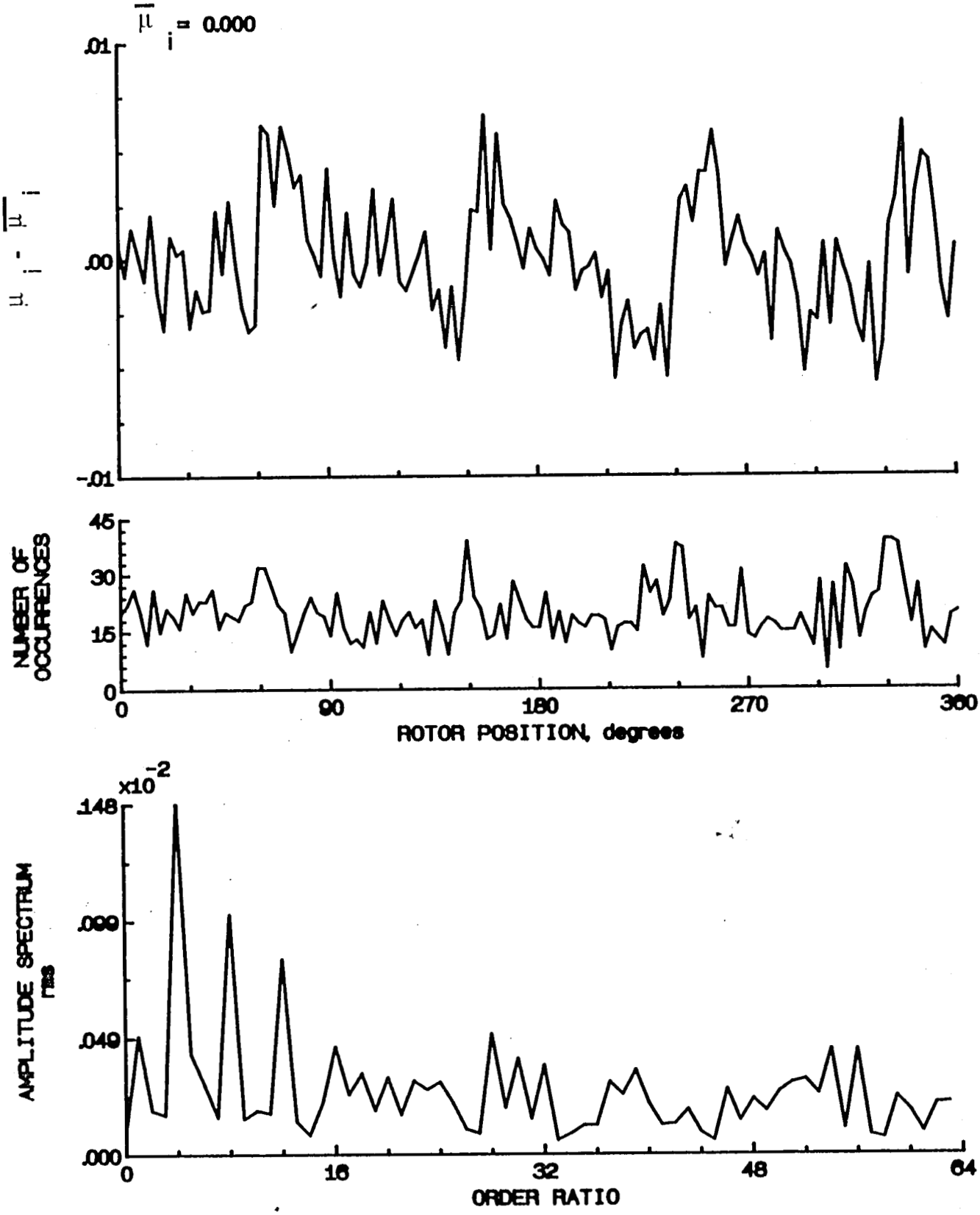
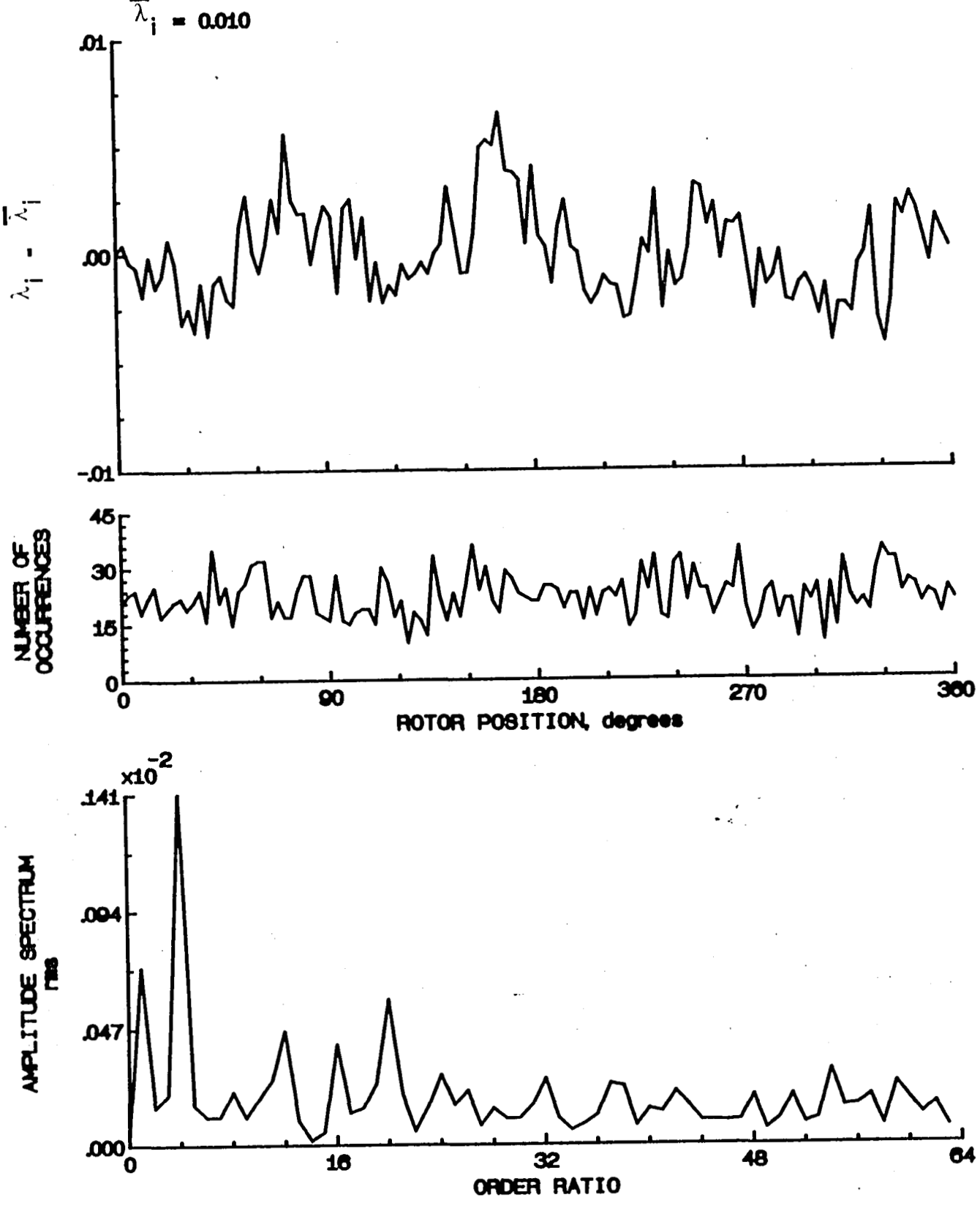


Figure 145.- Induced inflow velocity measured at 240 degrees and r/R of 1.02.



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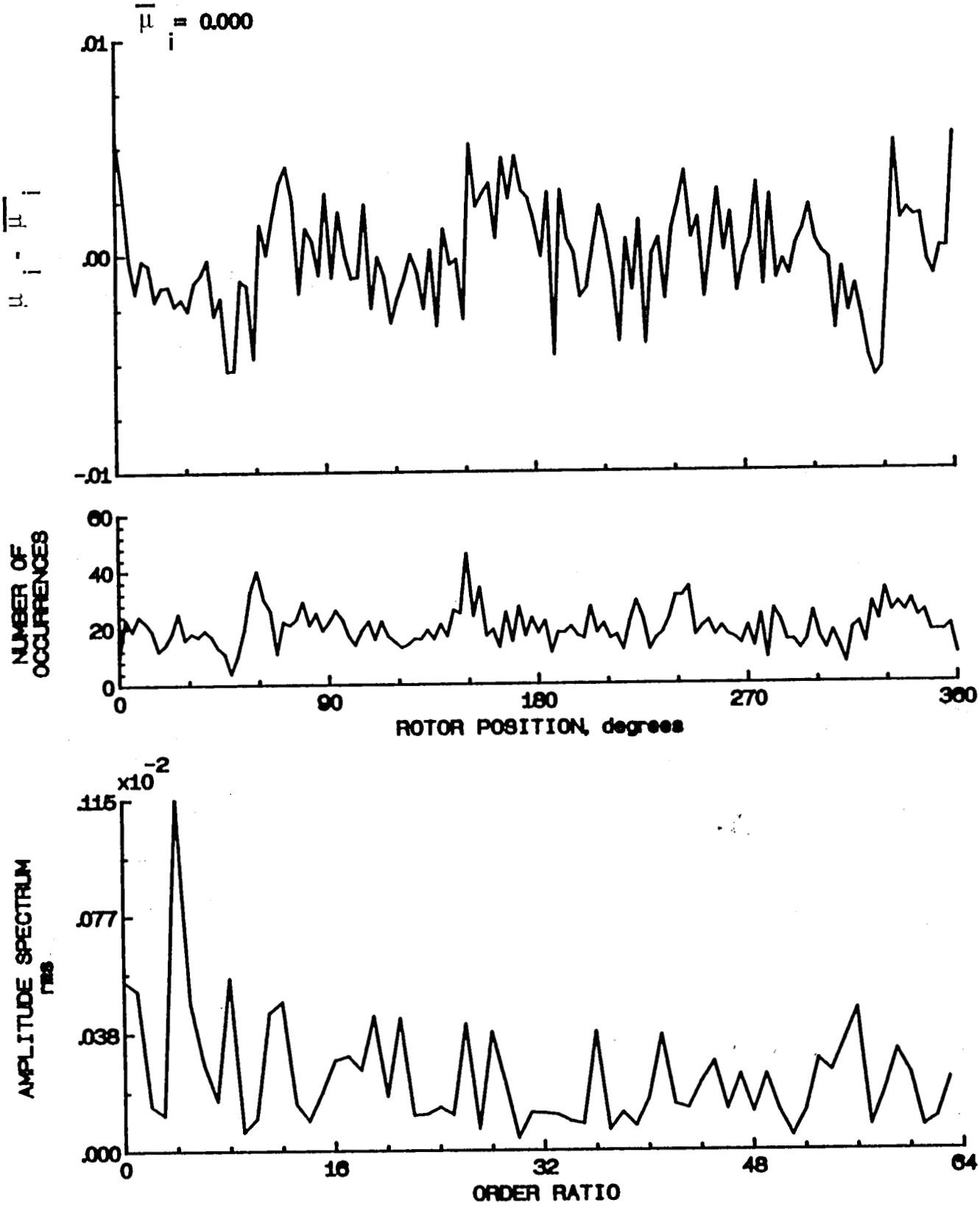
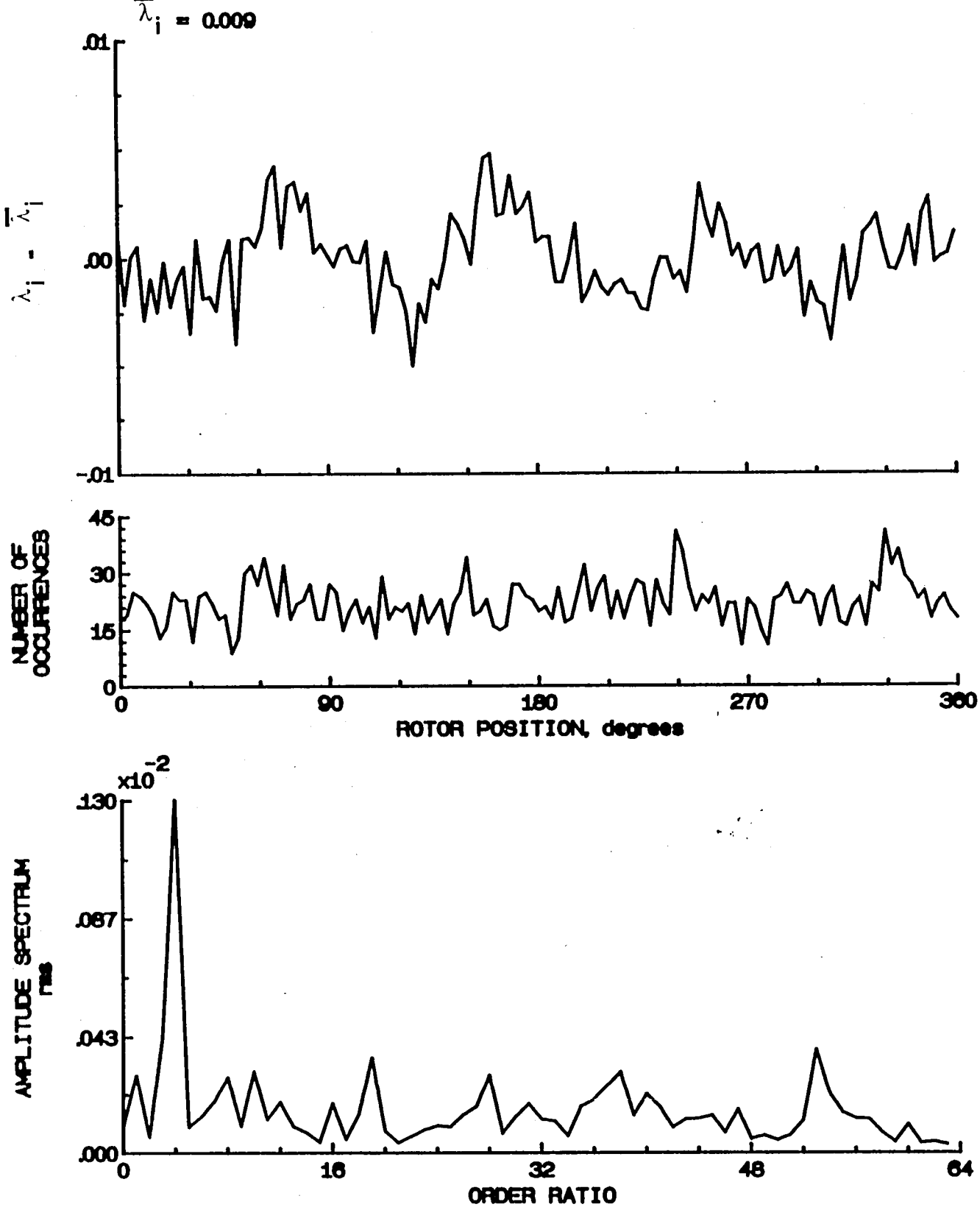


Figure 146.- Induced inflow velocity measured at 240 degrees and r/R of 1.04.



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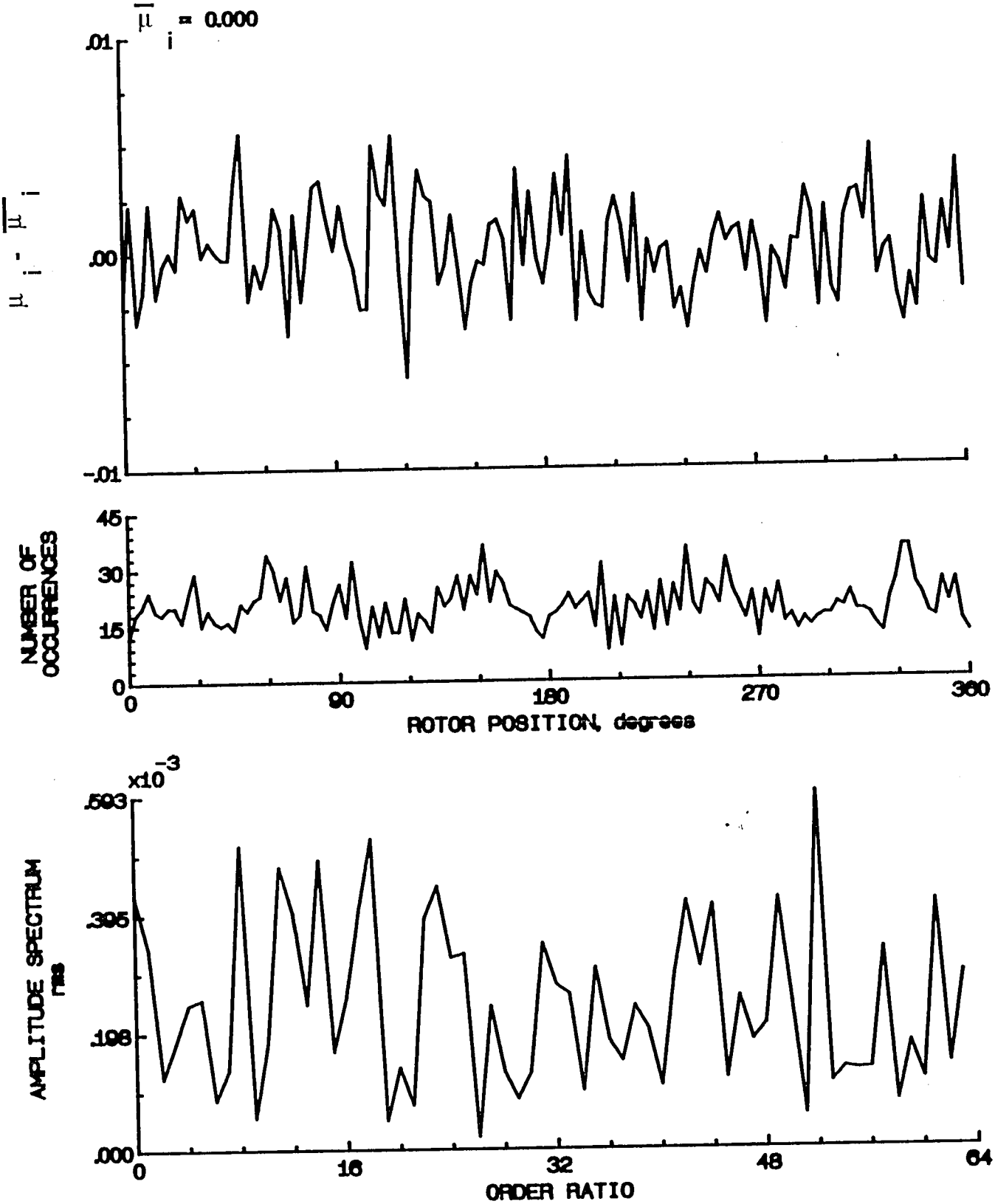
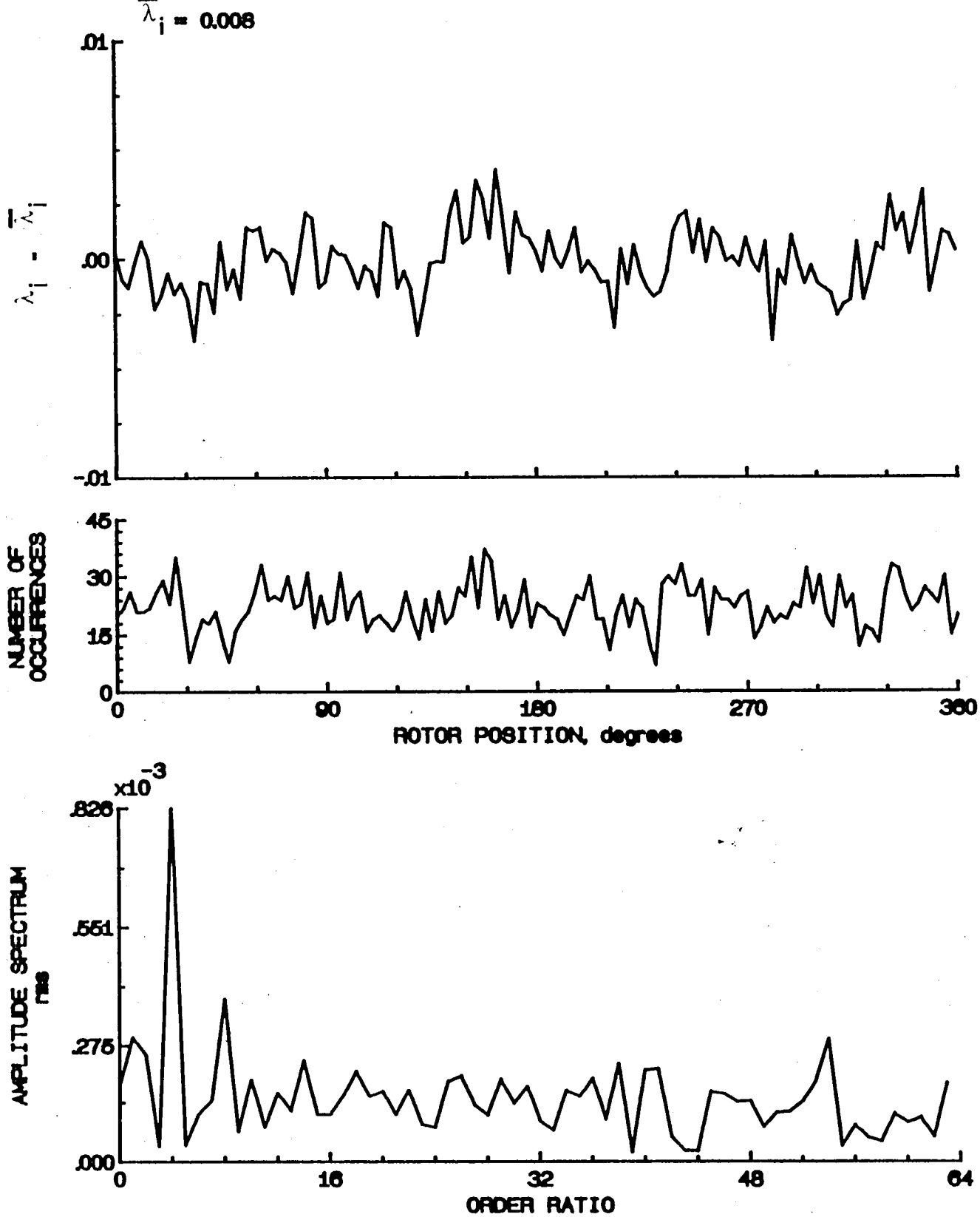


Figure 147.- Induced inflow velocity measured at 240 degrees and r/R of 1.10.



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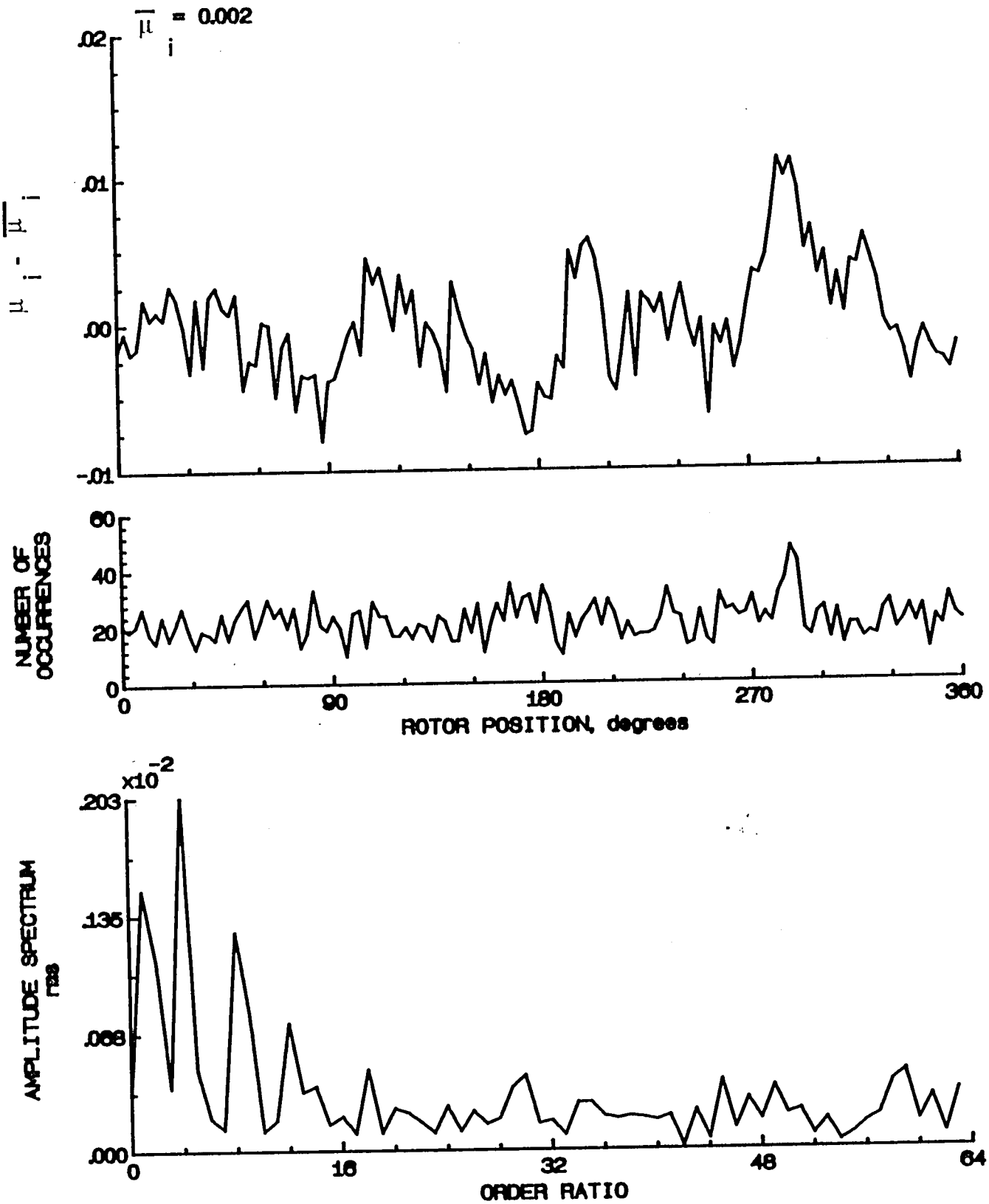
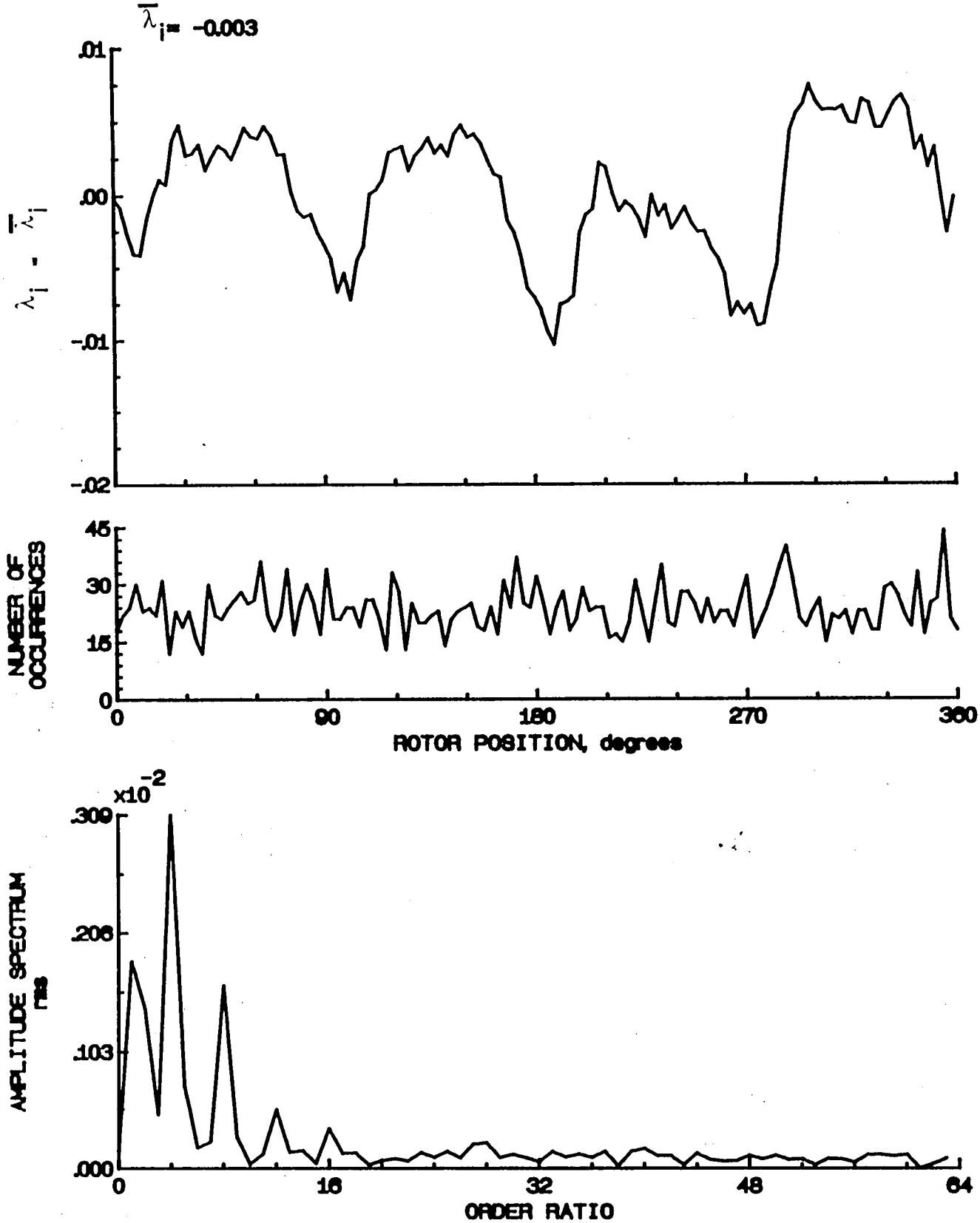


Figure 148.- Induced inflow velocity measured at 270 degrees and r/R of 0.20.



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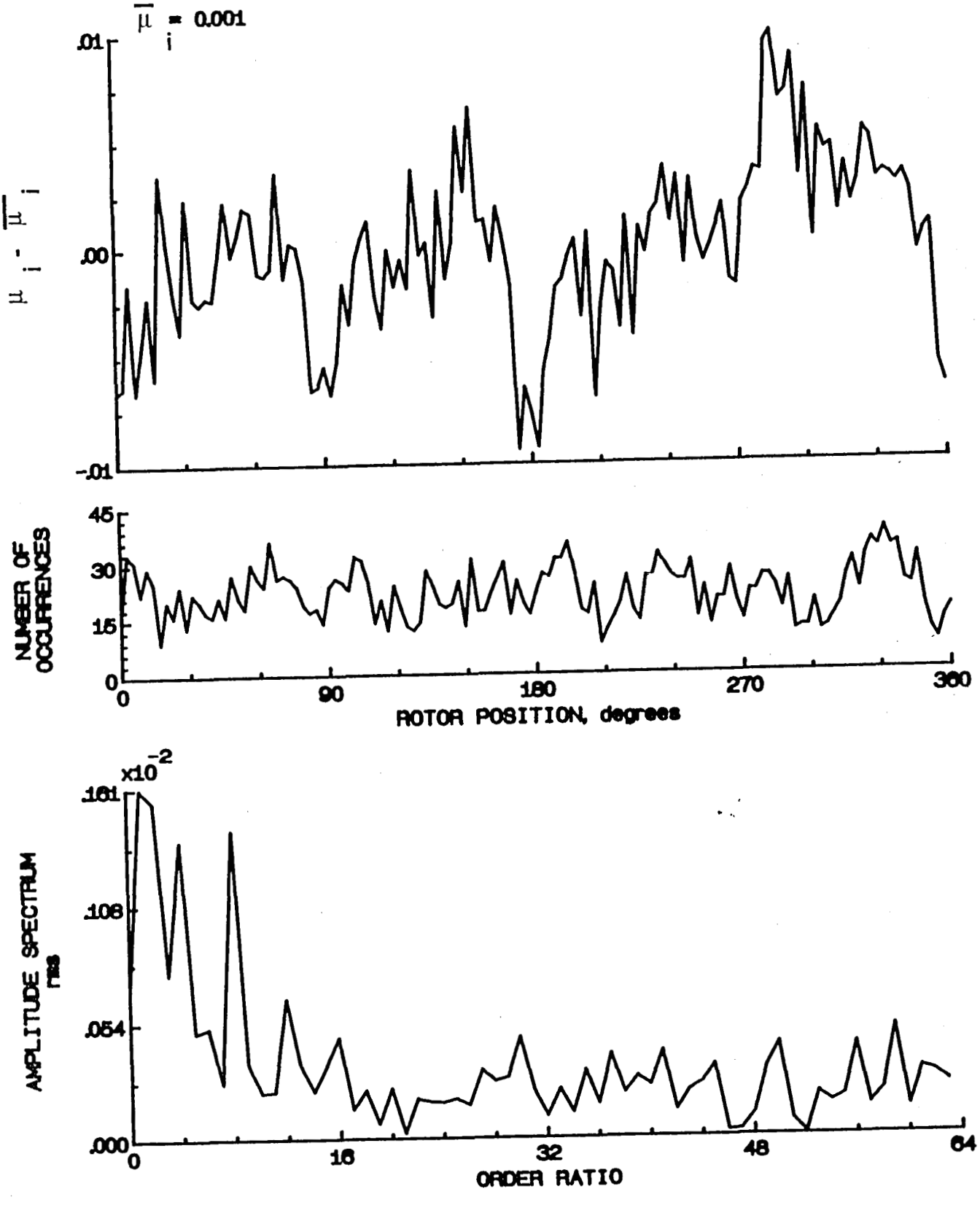


Figure 149.- Induced inflow velocity measured at 270 degrees and r/R of 0.40.

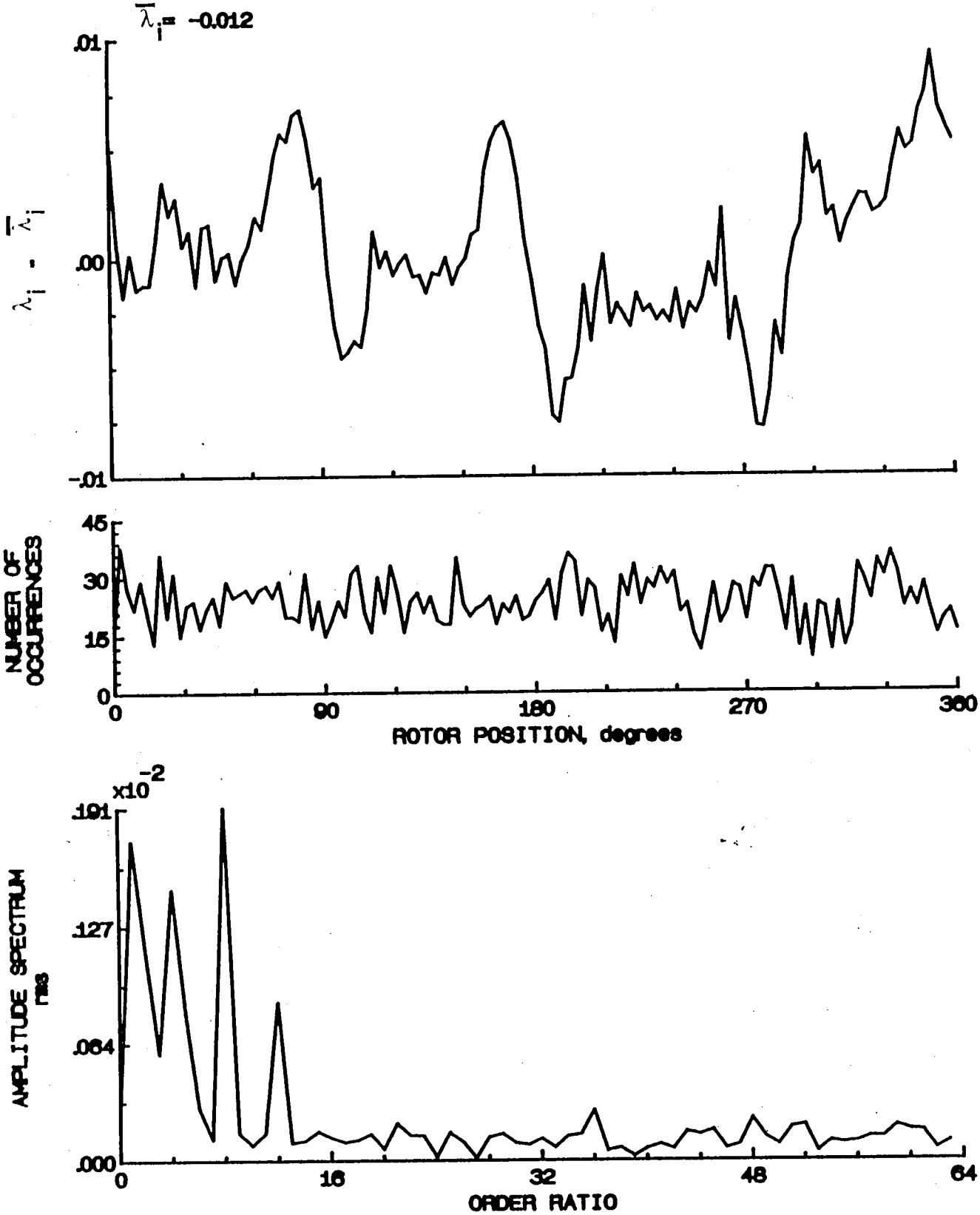


Figure 149.- Concluded.

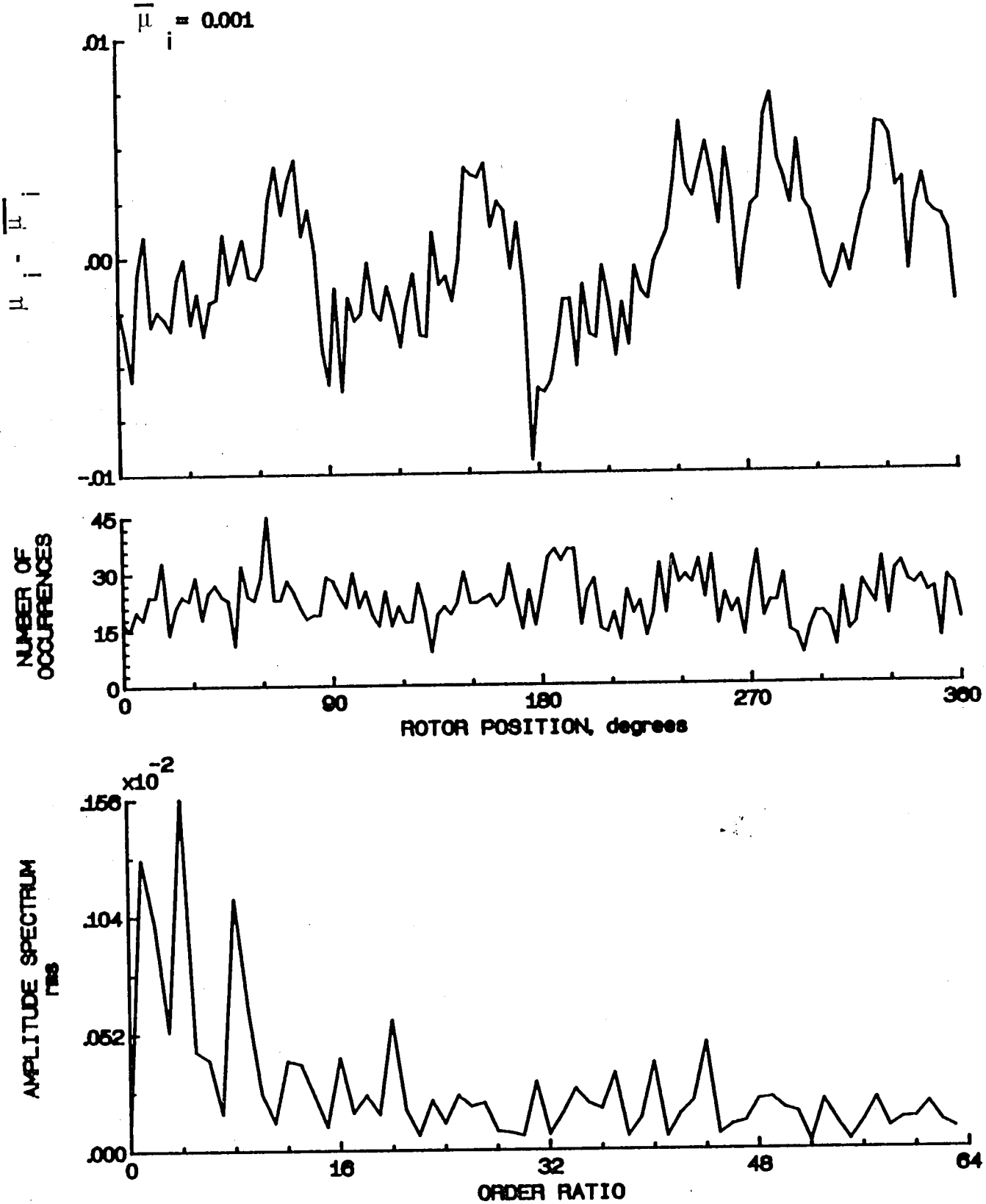
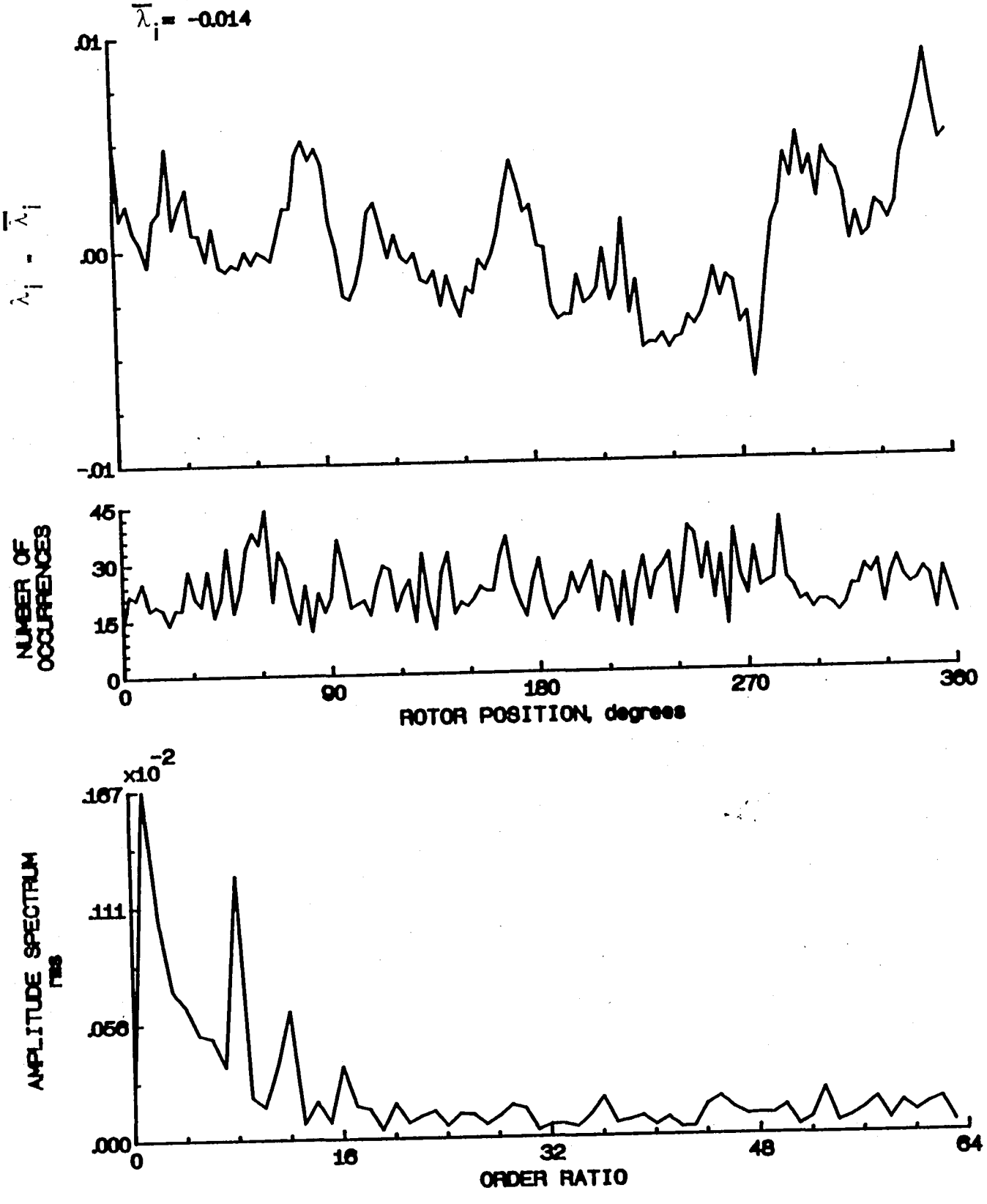


Figure 150.- Induced inflow velocity measured at 270 degrees and r/R of 0.50.



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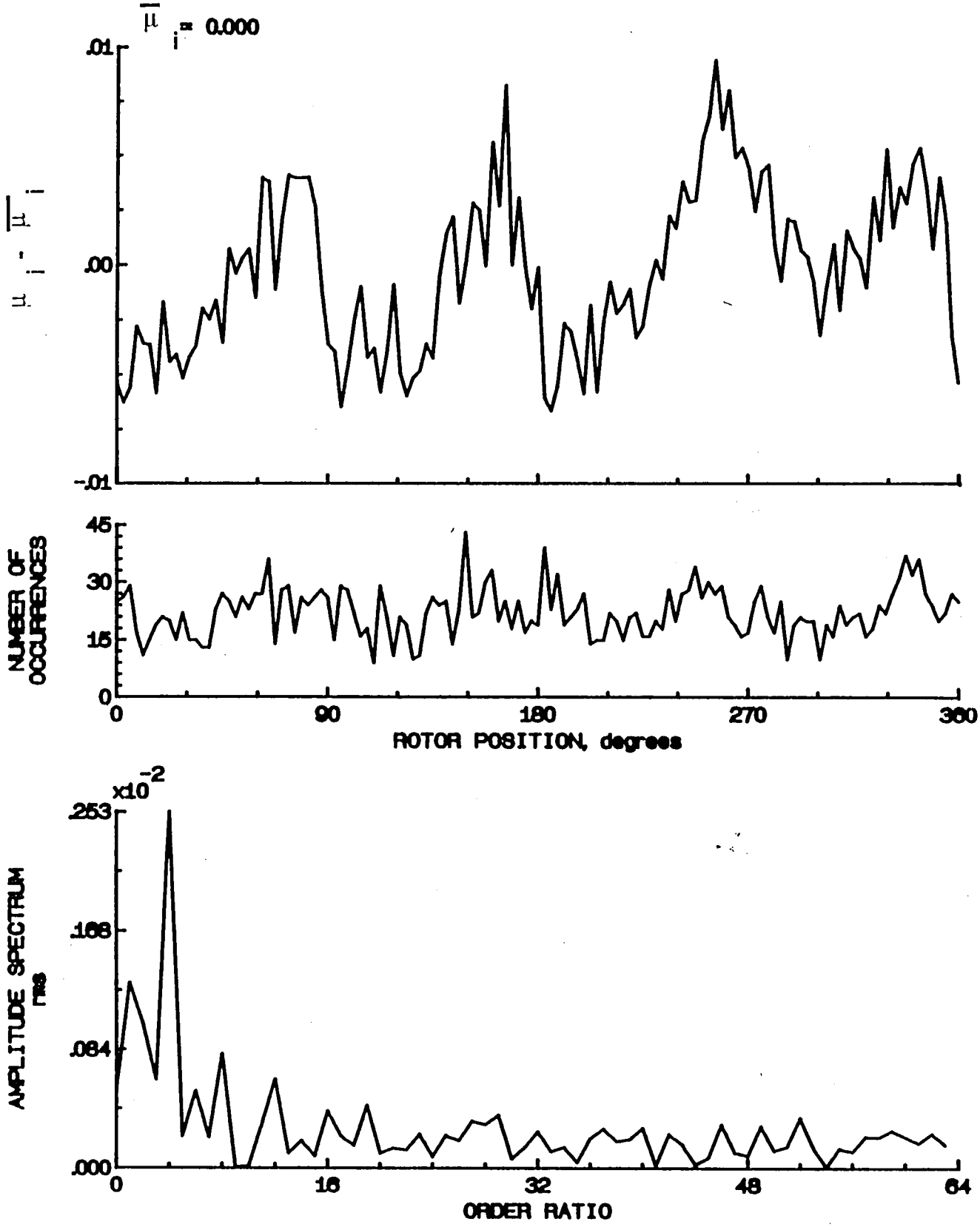
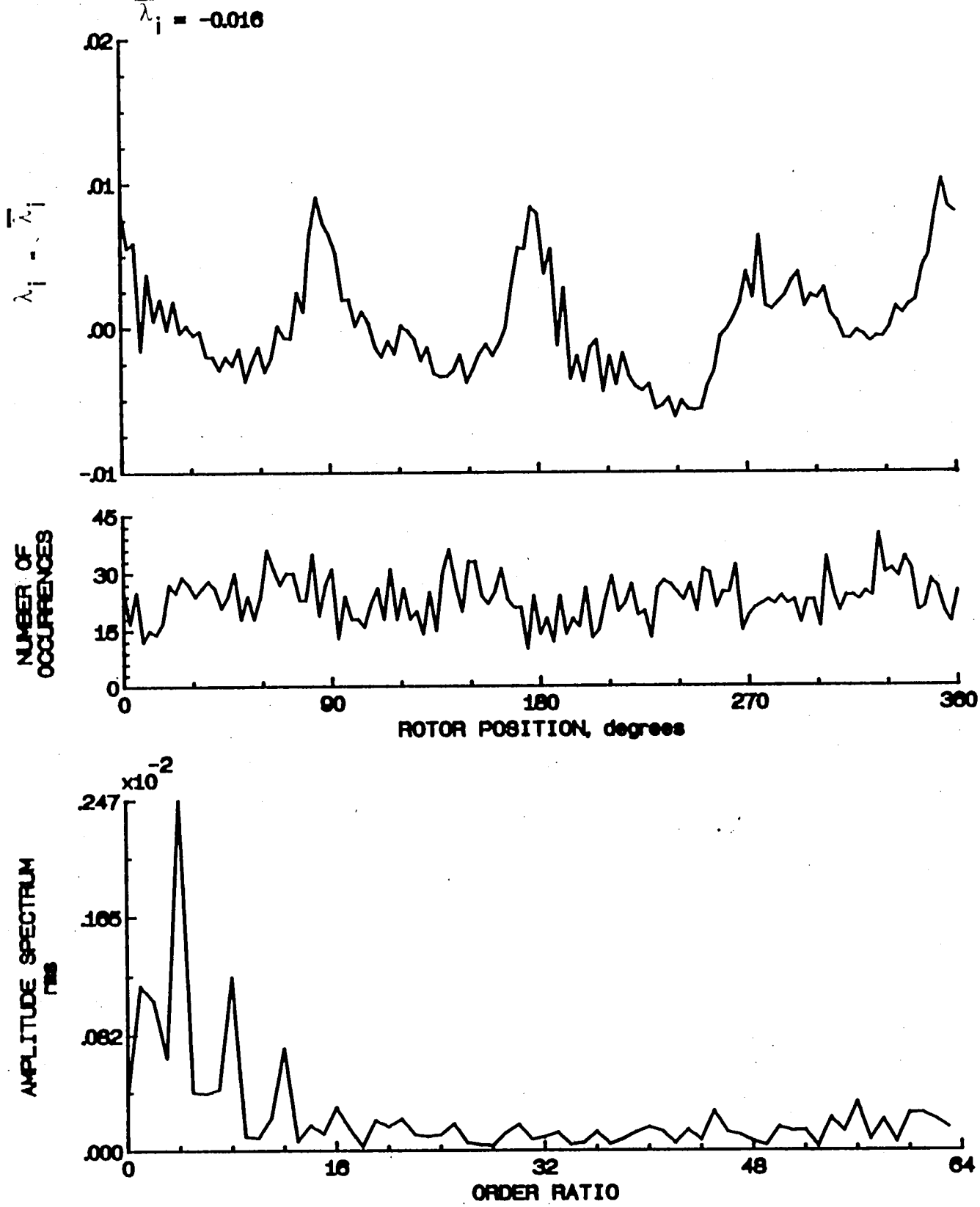


Figure 151.- Induced inflow velocity measured at 270 degrees and r/R of 0.60.



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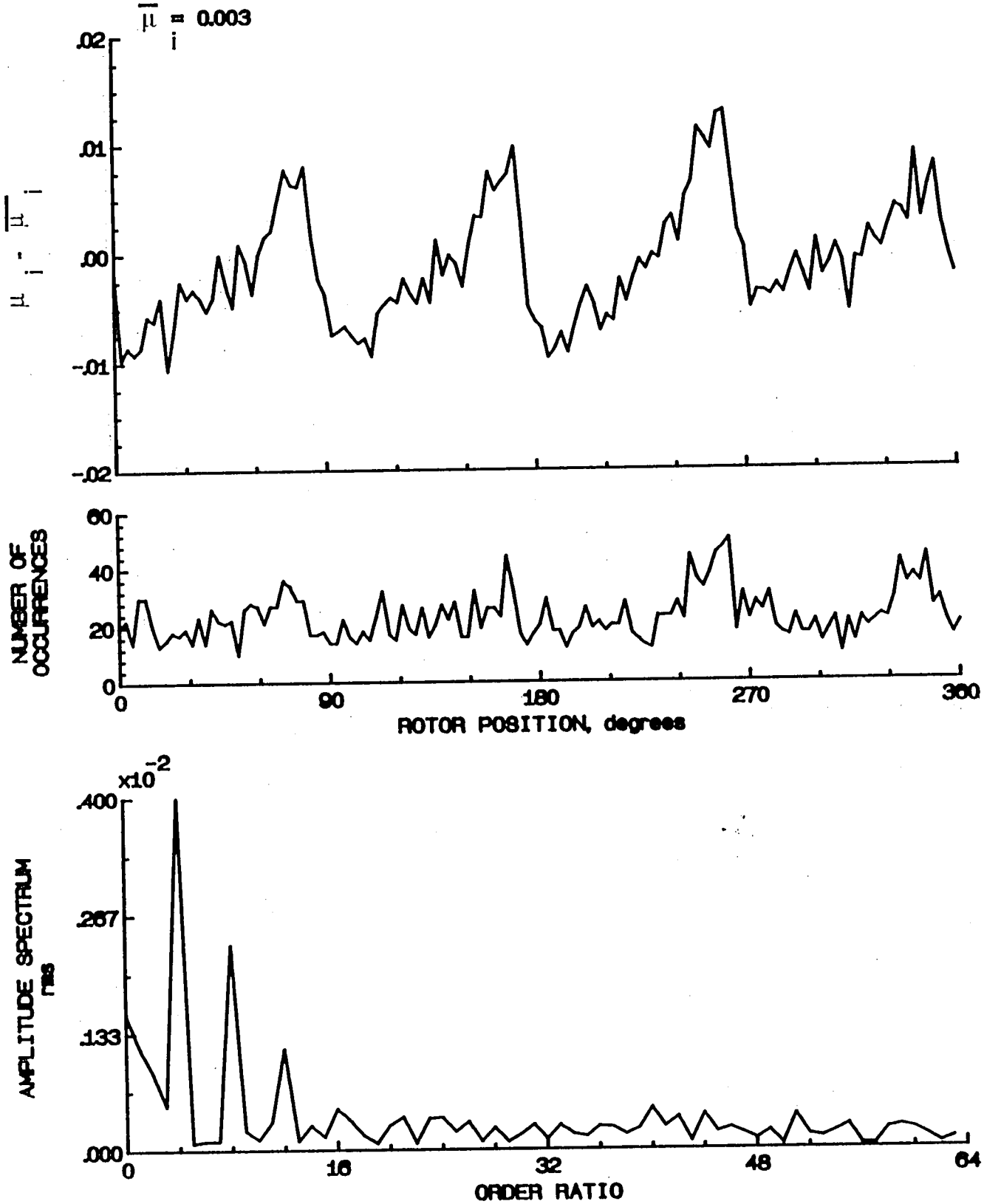


Figure 152.- Induced inflow velocity measured at 270 degrees and r/R of 0.70.

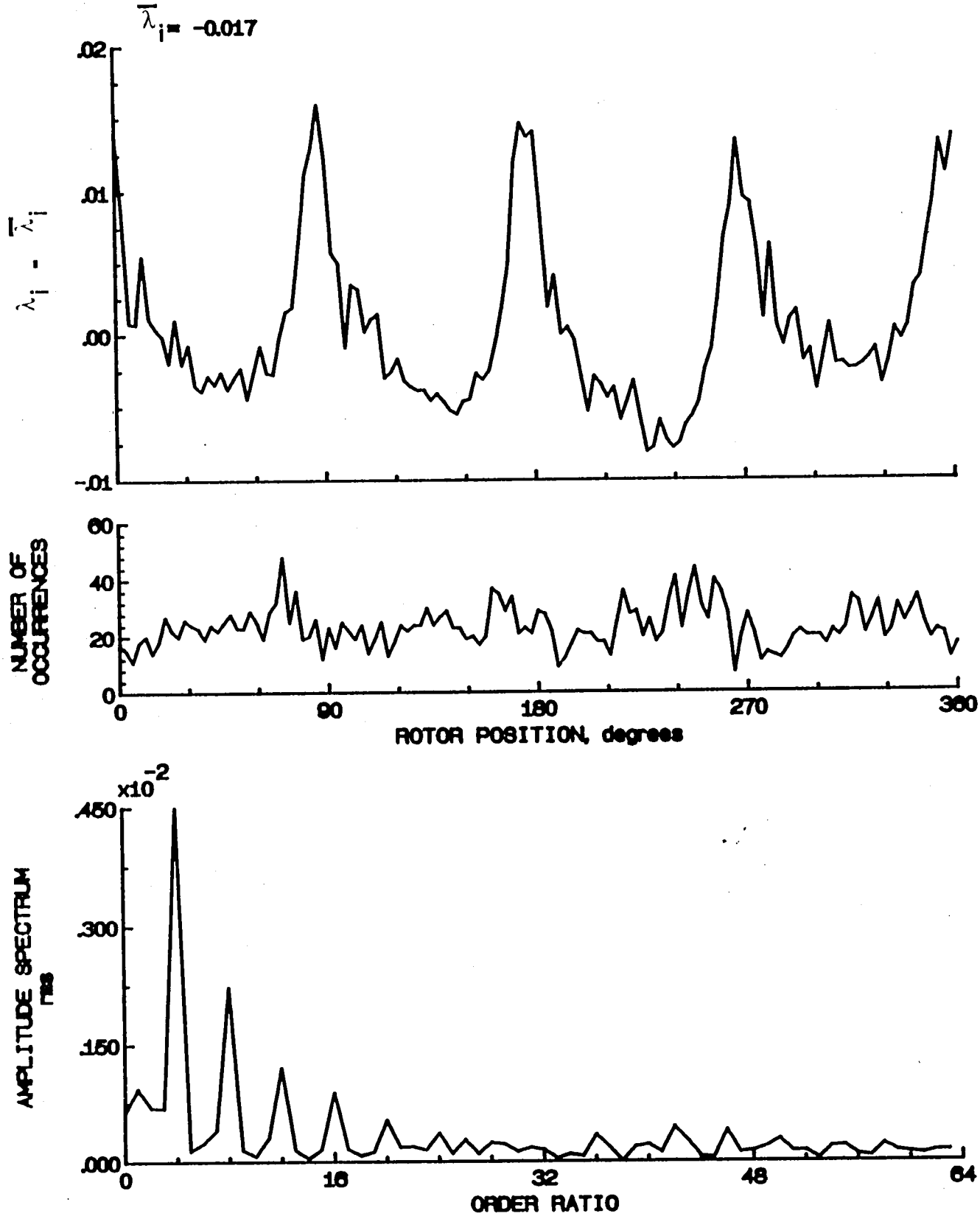


Figure 152.- Concluded.

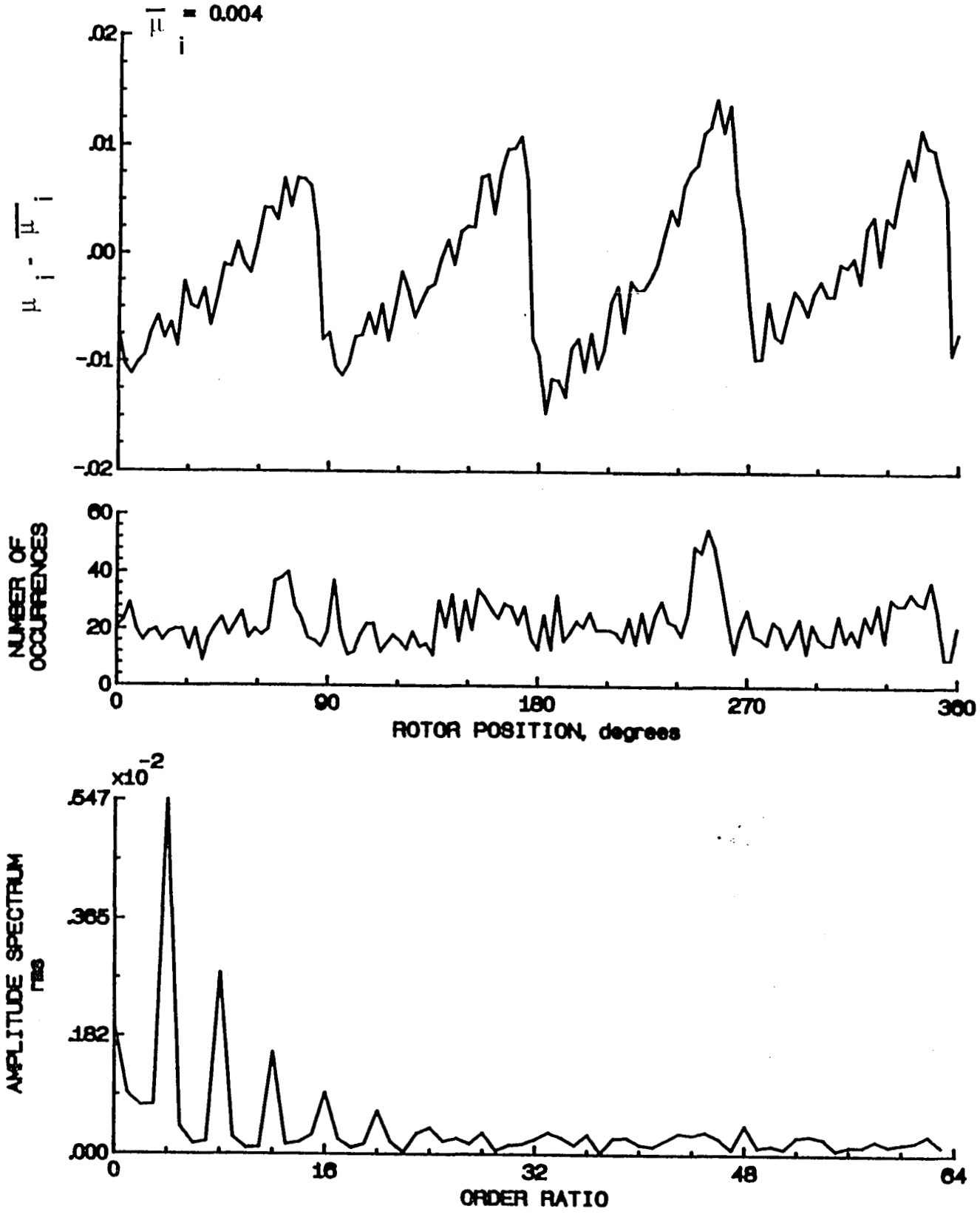


Figure 153.- Induced inflow velocity measured at 270 degrees and r/R of 0.74.

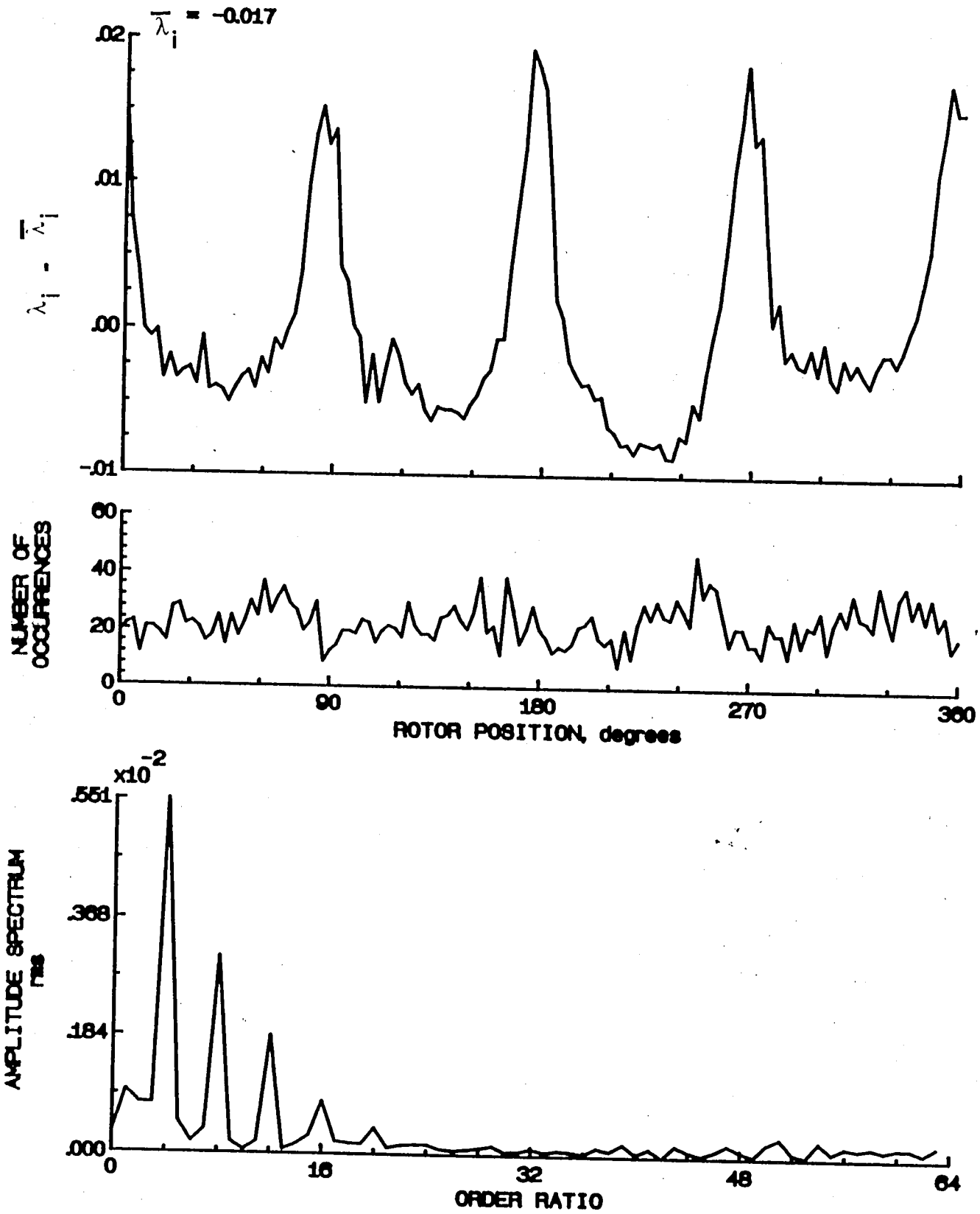


Figure 153.- Concluded.

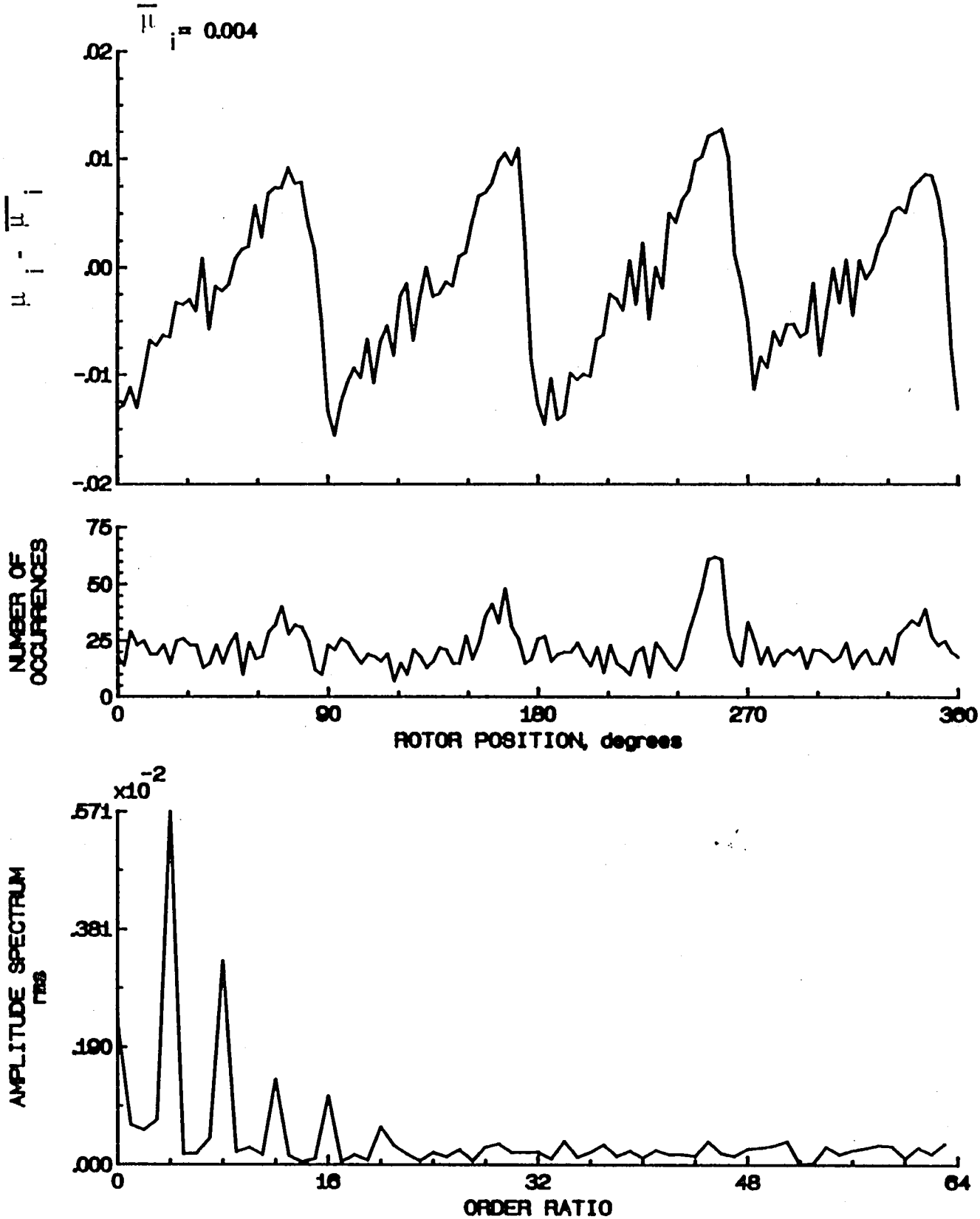


Figure 154.- Induced inflow velocity measured at 270 degrees and r/R of 0.78.

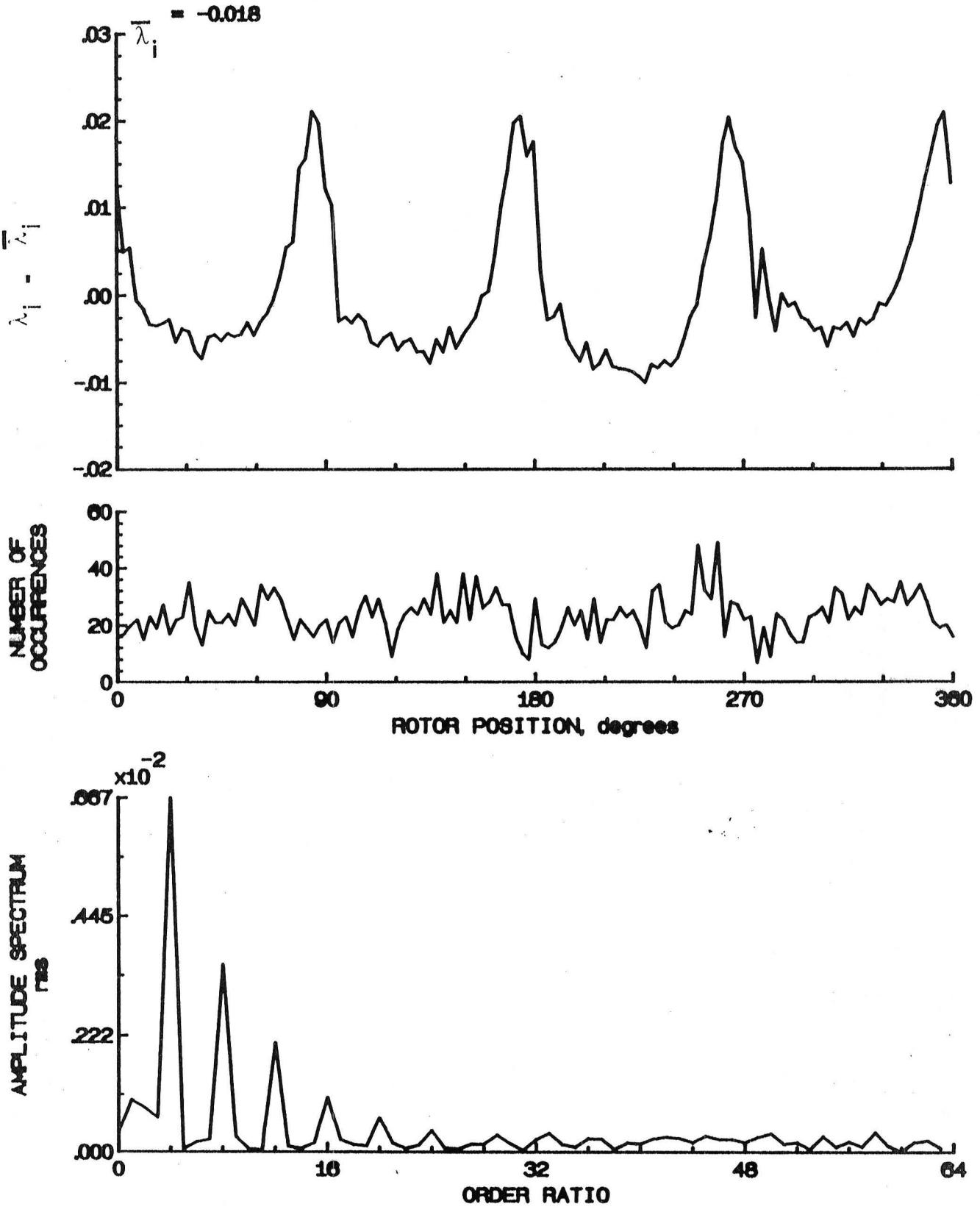


Figure 154.- Concluded.

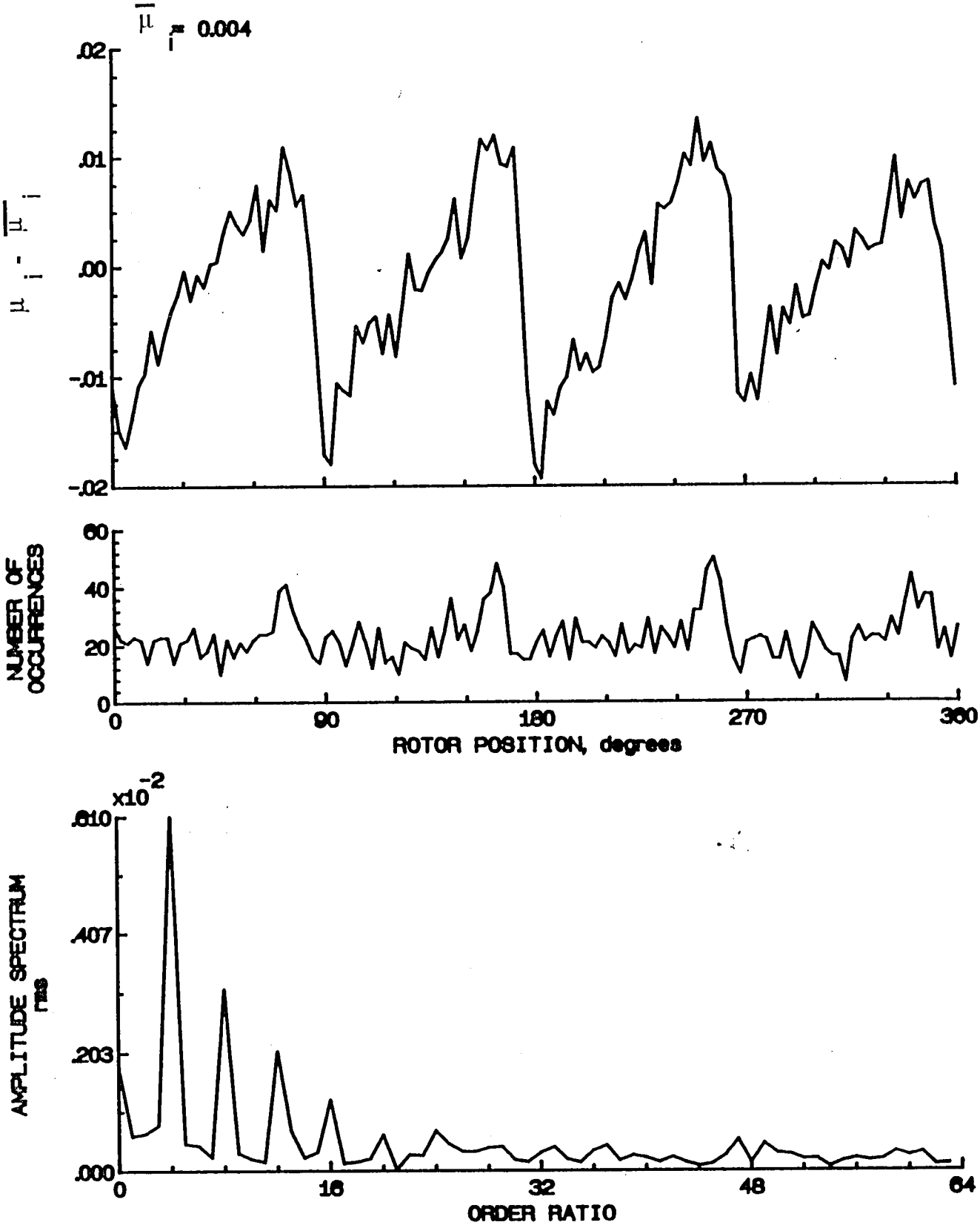
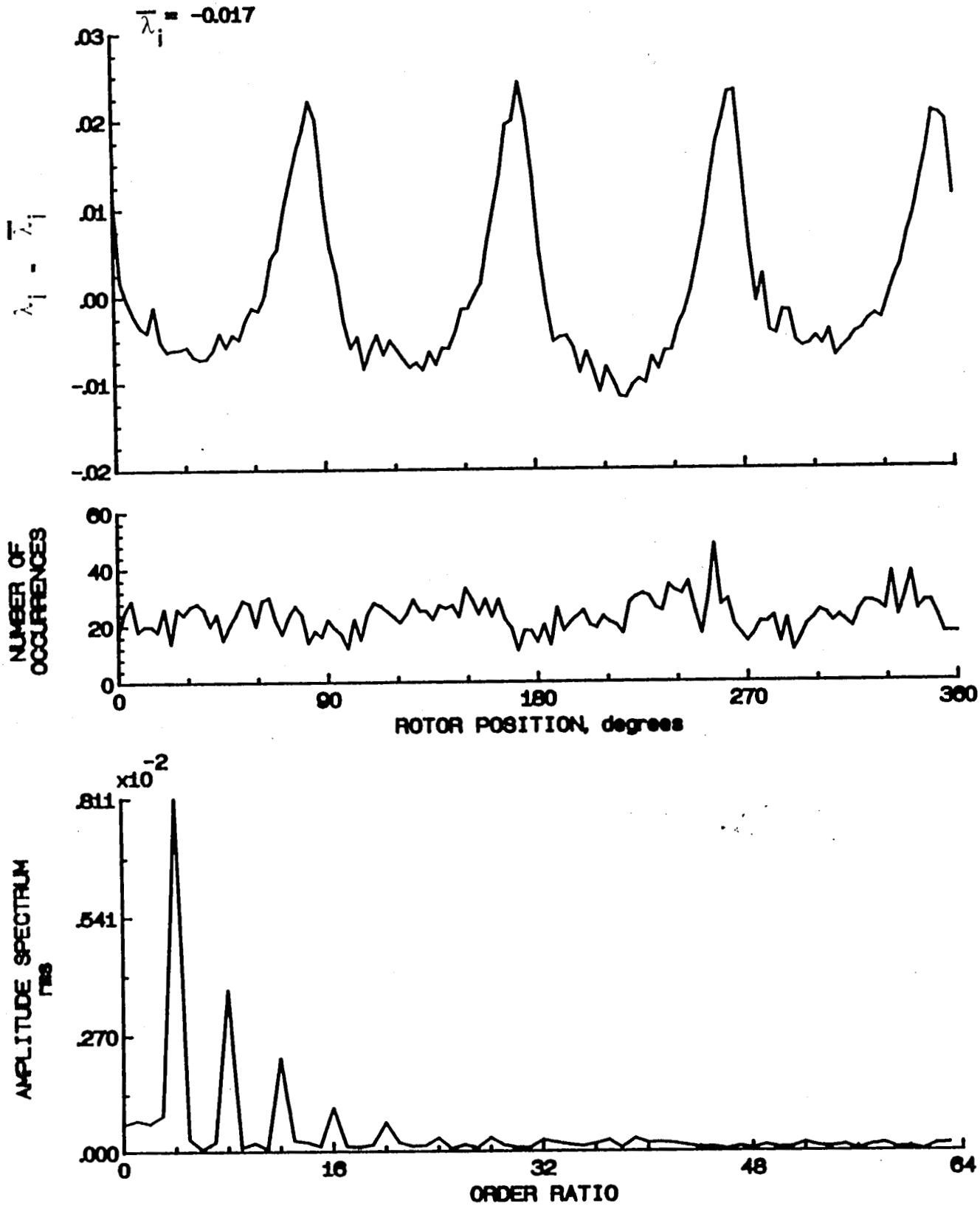


Figure 155.- Induced inflow velocity measured at 270 degrees and r/R of 0.82.



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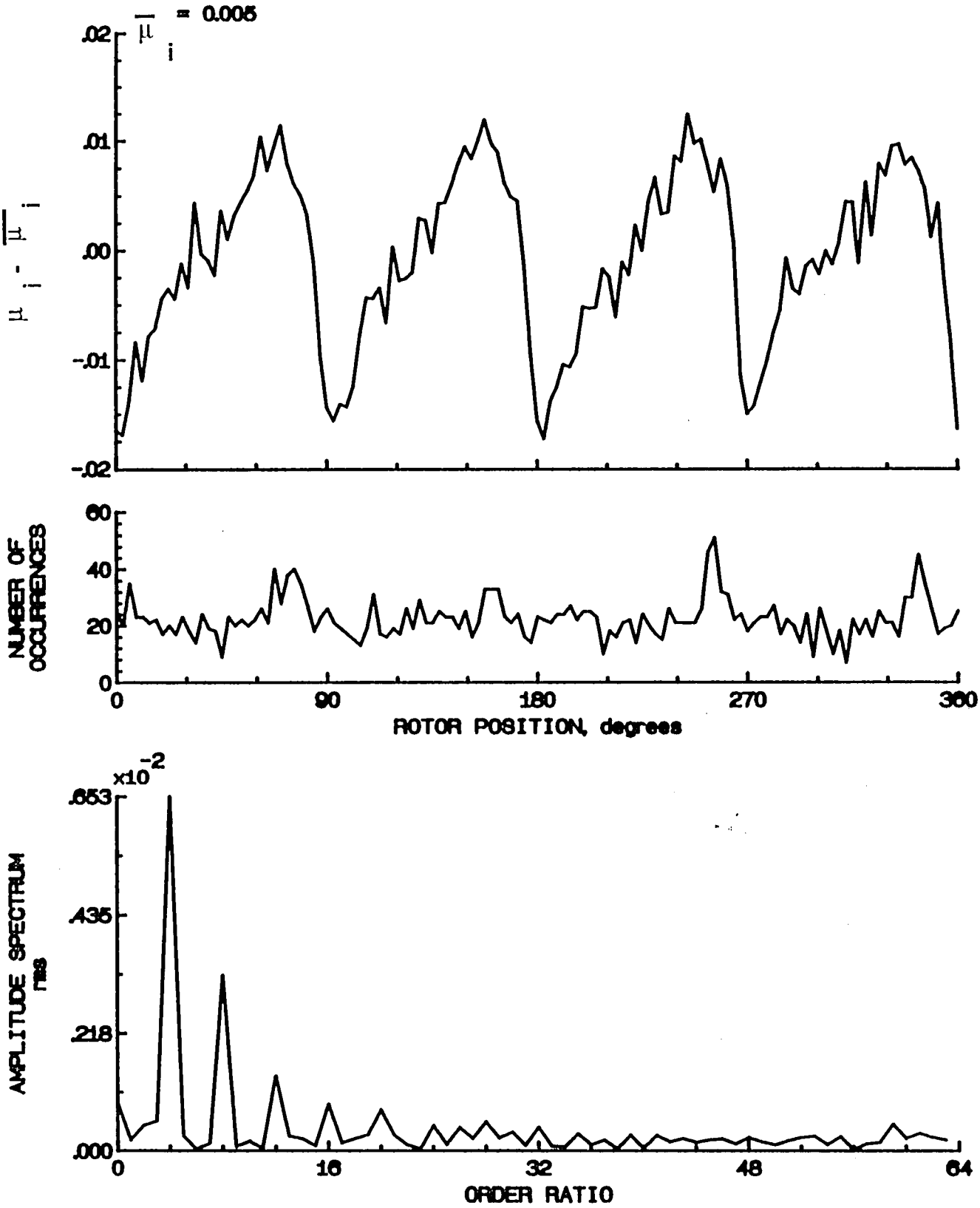


Figure 156.- Induced inflow velocity measured at 270 degrees and r/R of 0.86.

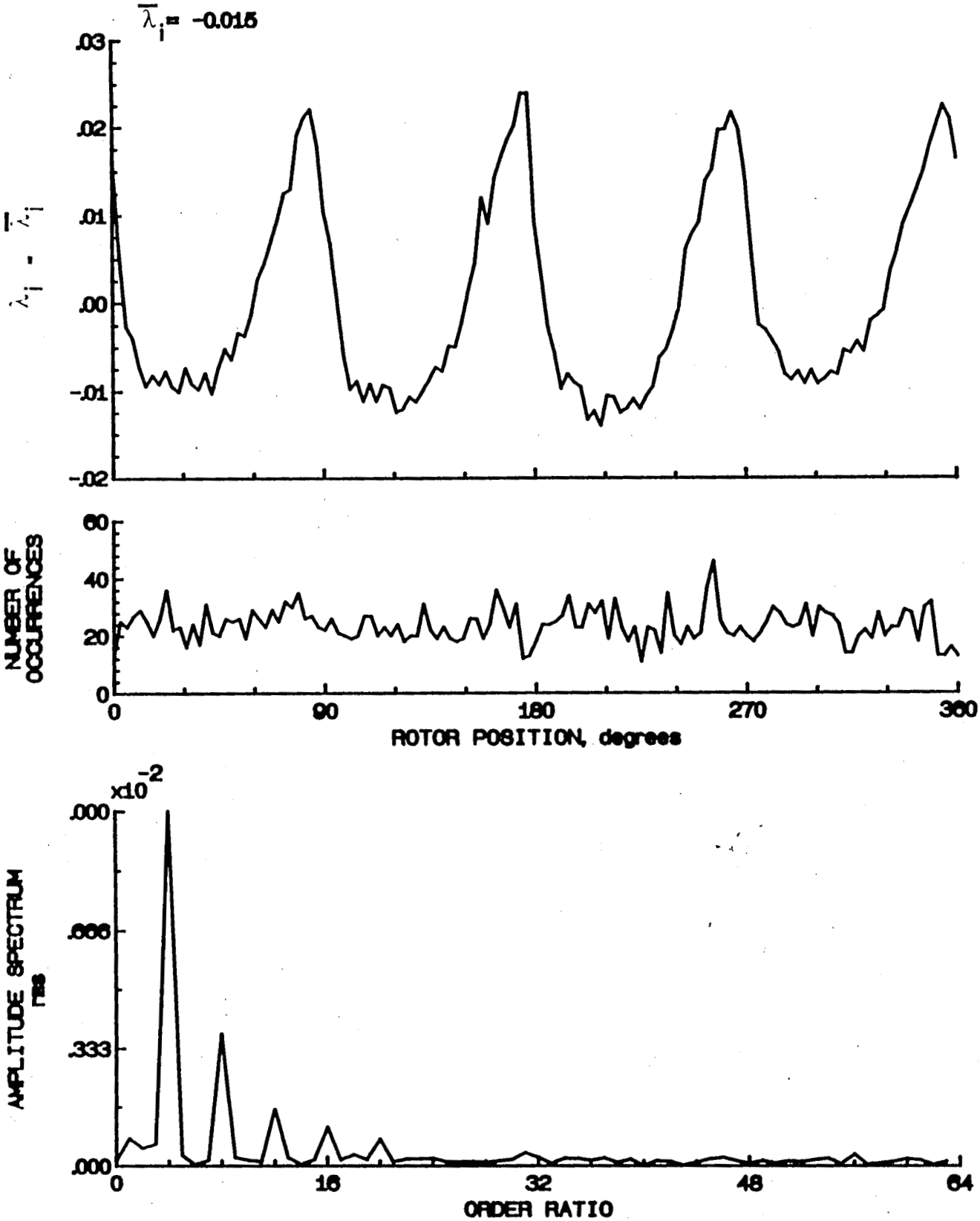


Figure 156.- Concluded.

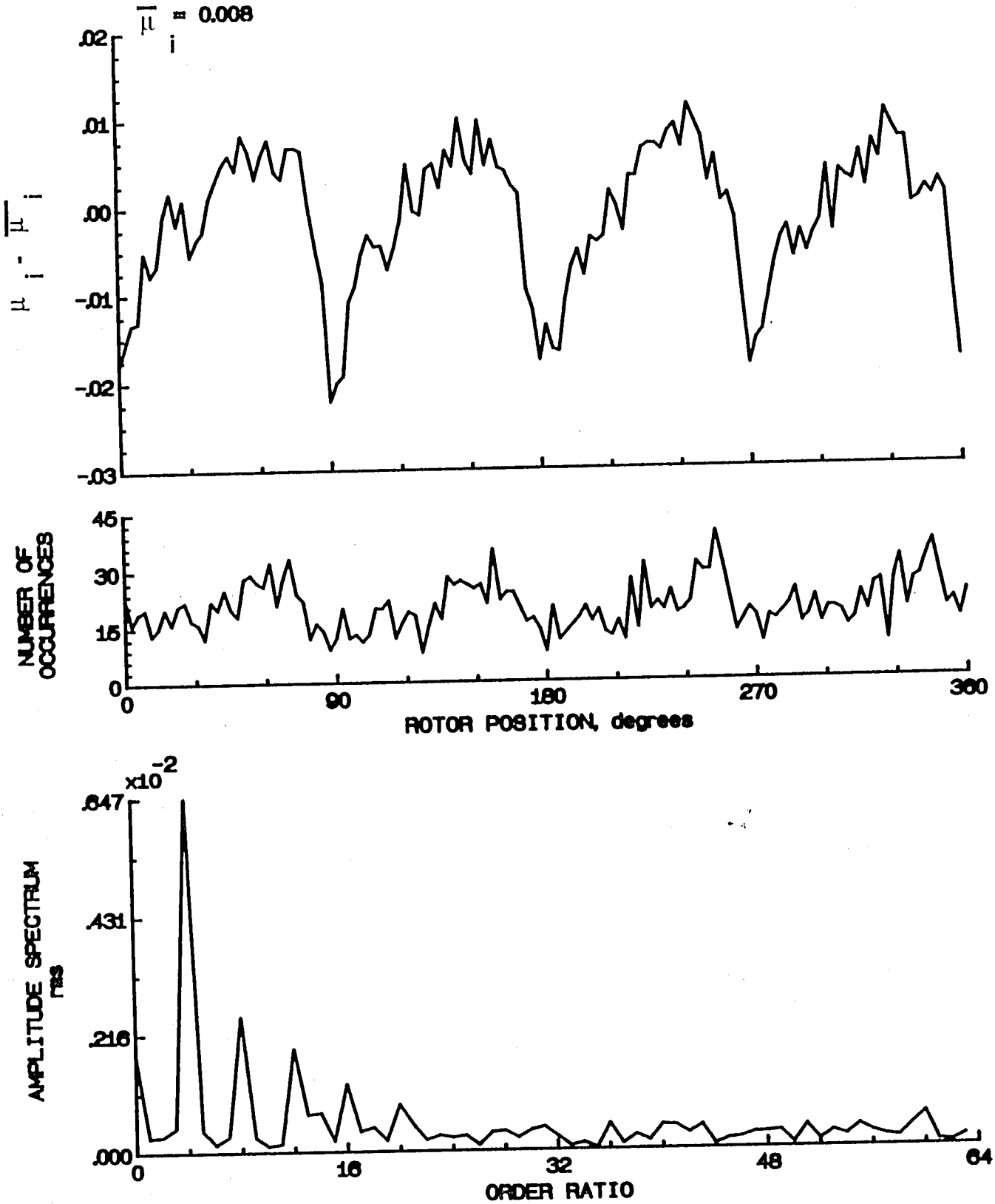


Figure 157.- Induced inflow velocity measured at 270 degrees and r/R of 0.90.

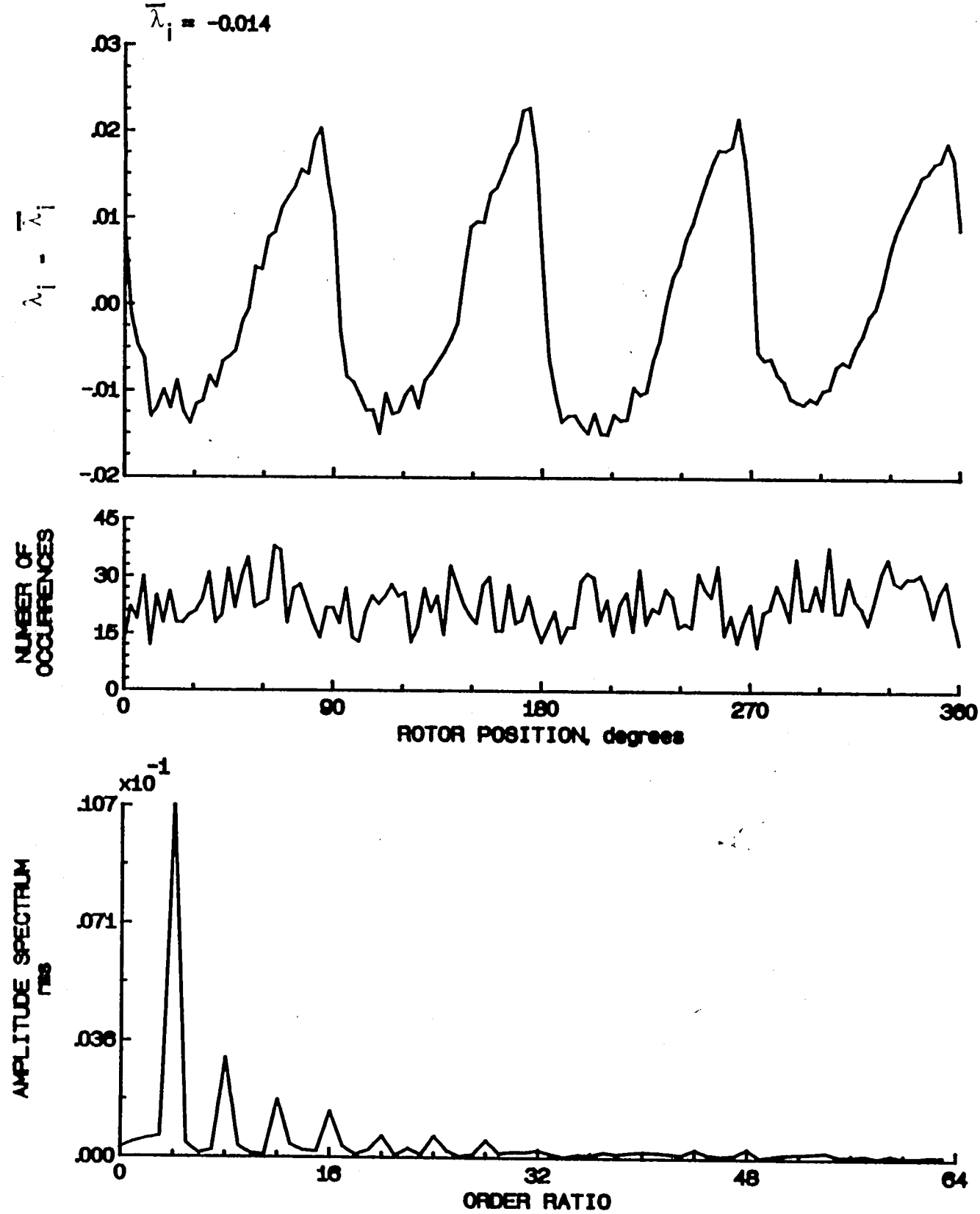


Figure 157.- Concluded.

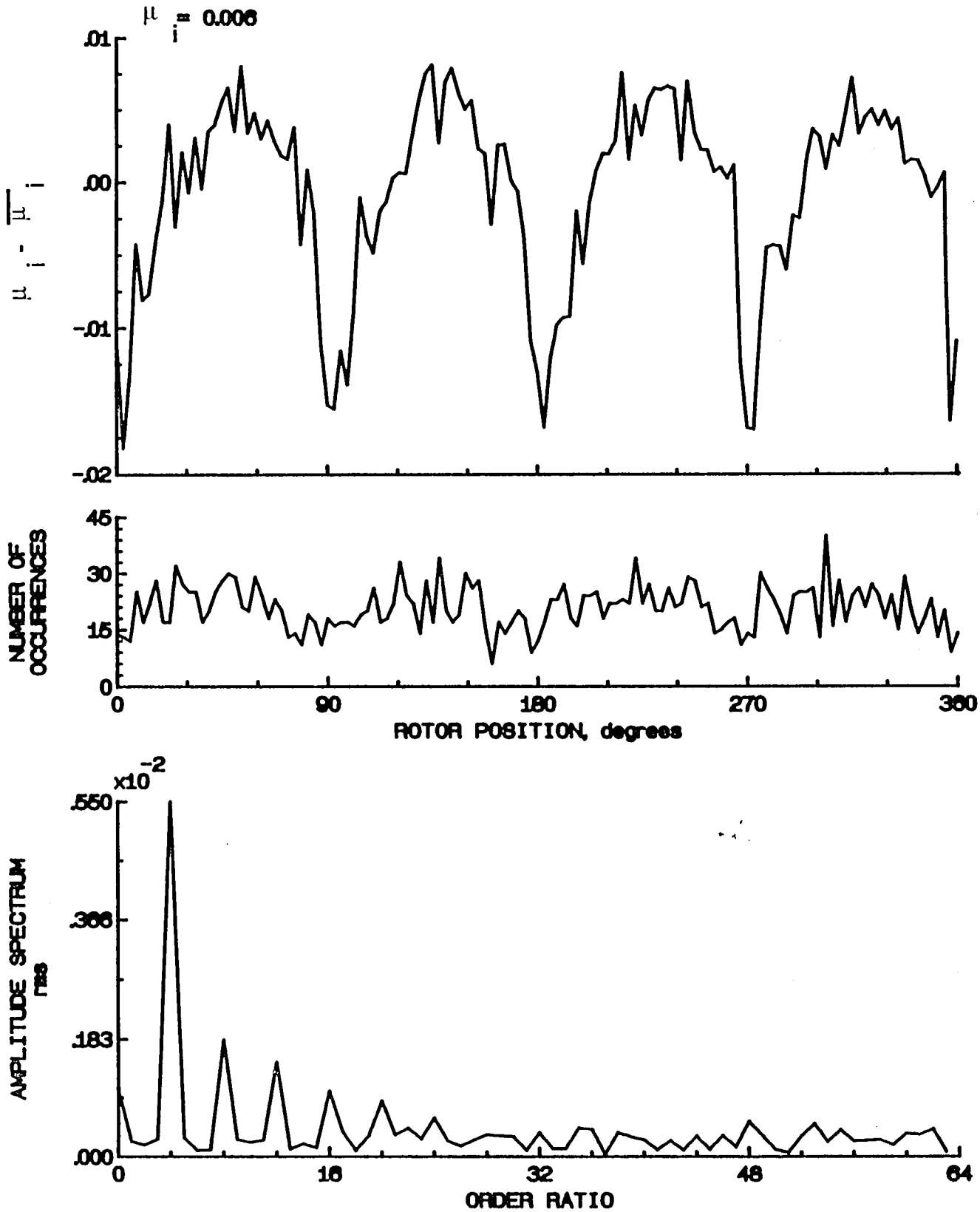


Figure 158.- Induced inflow velocity measured at 270 degrees and r/R of 0.94.

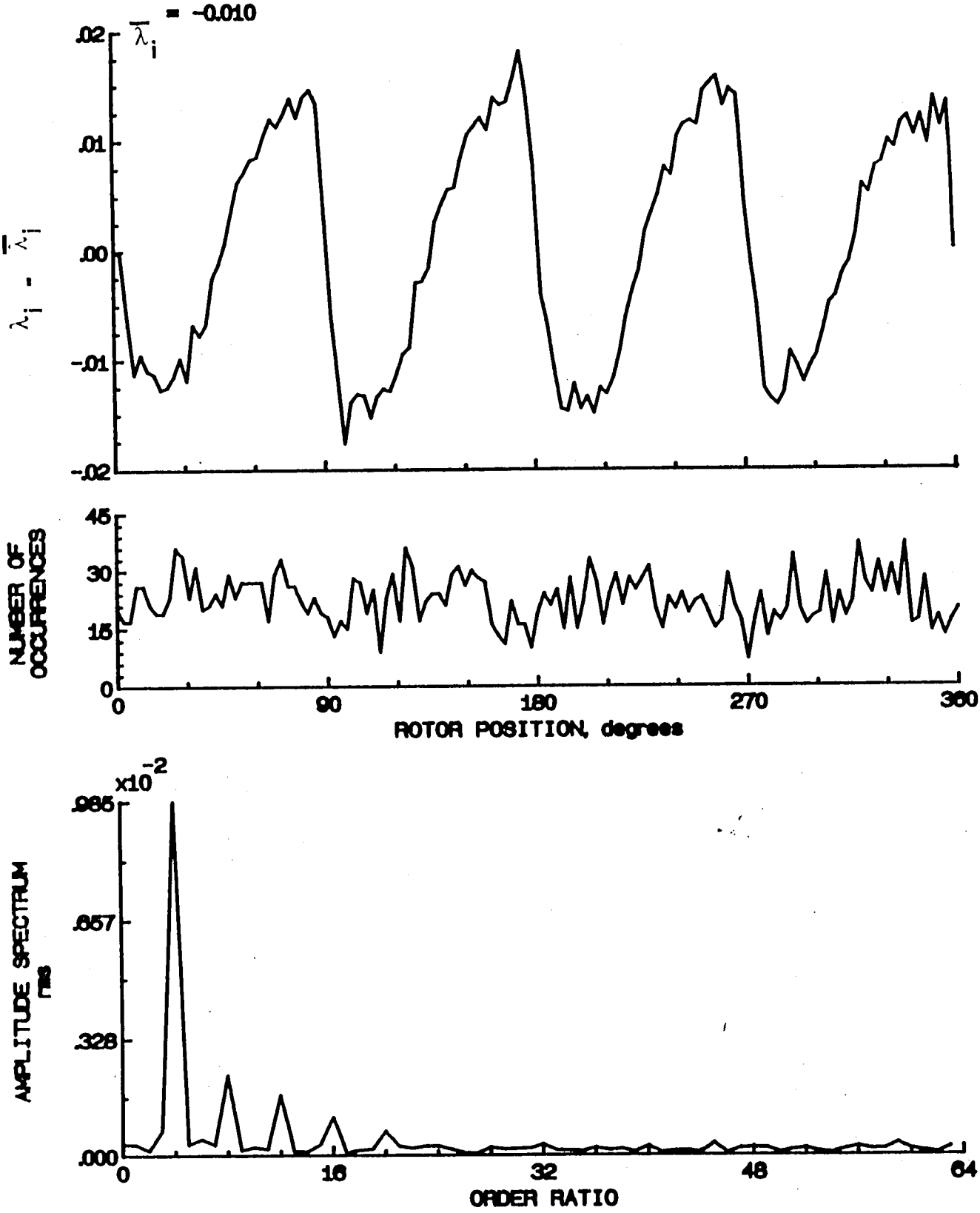


Figure 158.- Concluded.

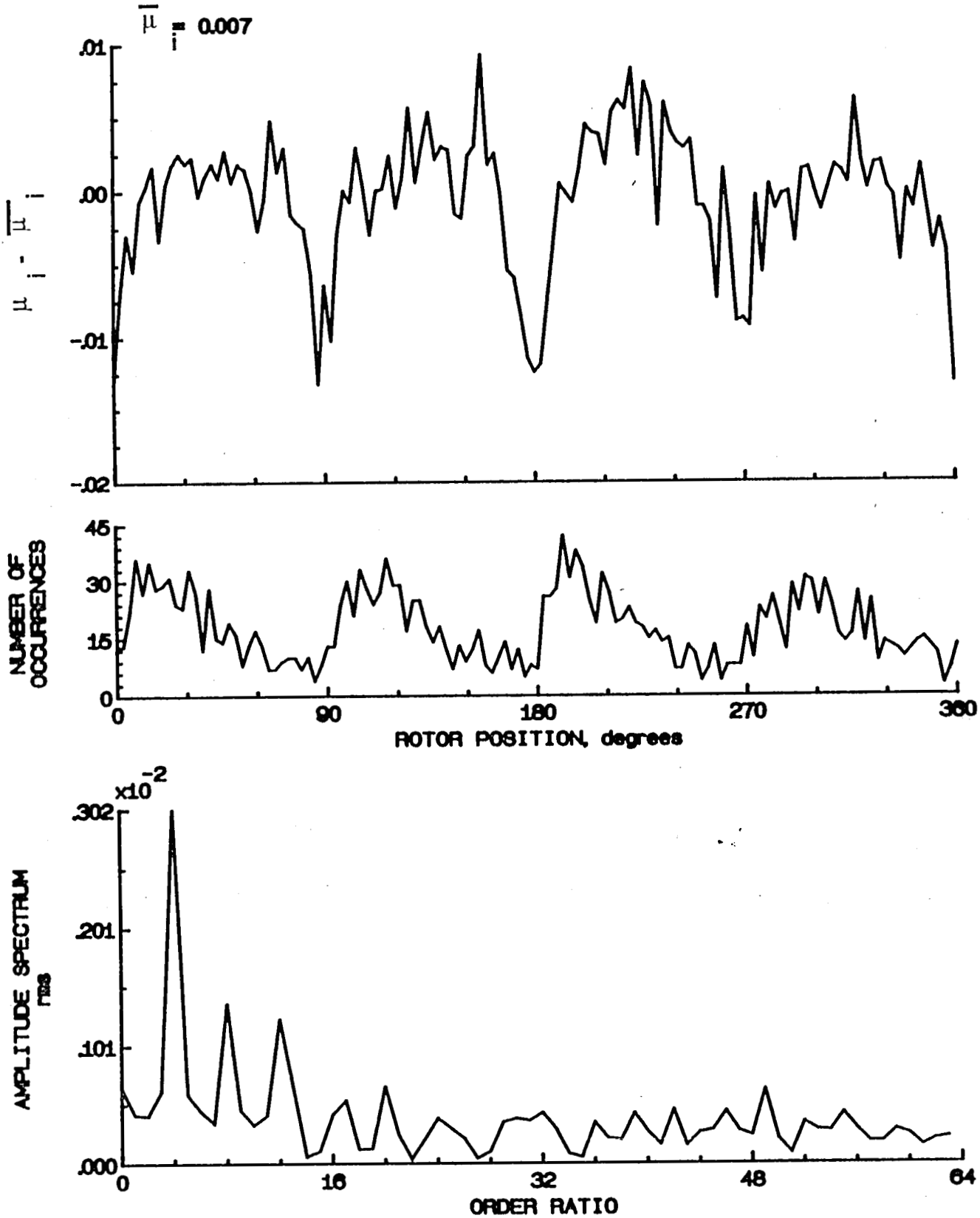


Figure 159.- Induced inflow velocity measured at 270 degrees and r/R of 0.98.

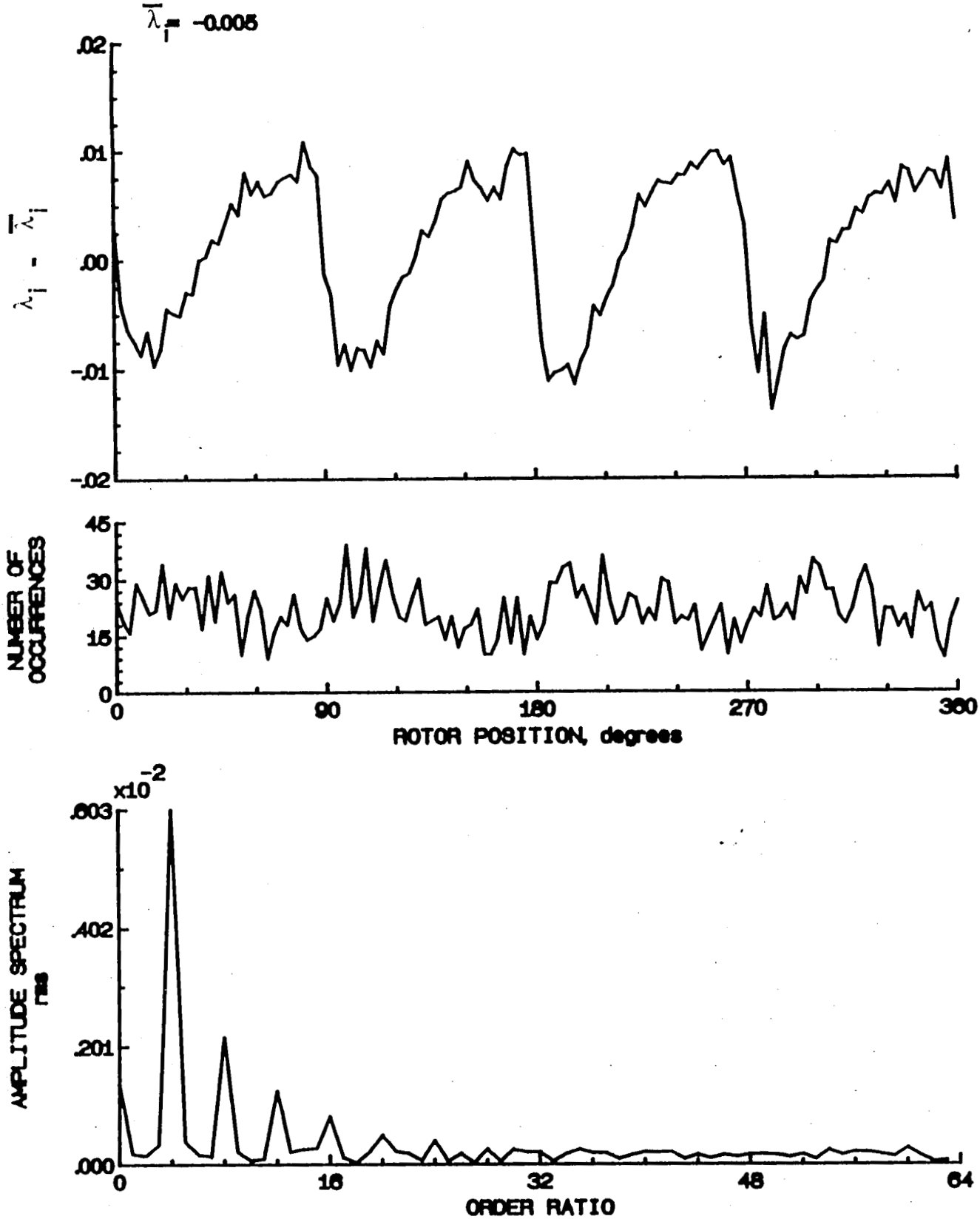


Figure 159.- Concluded.

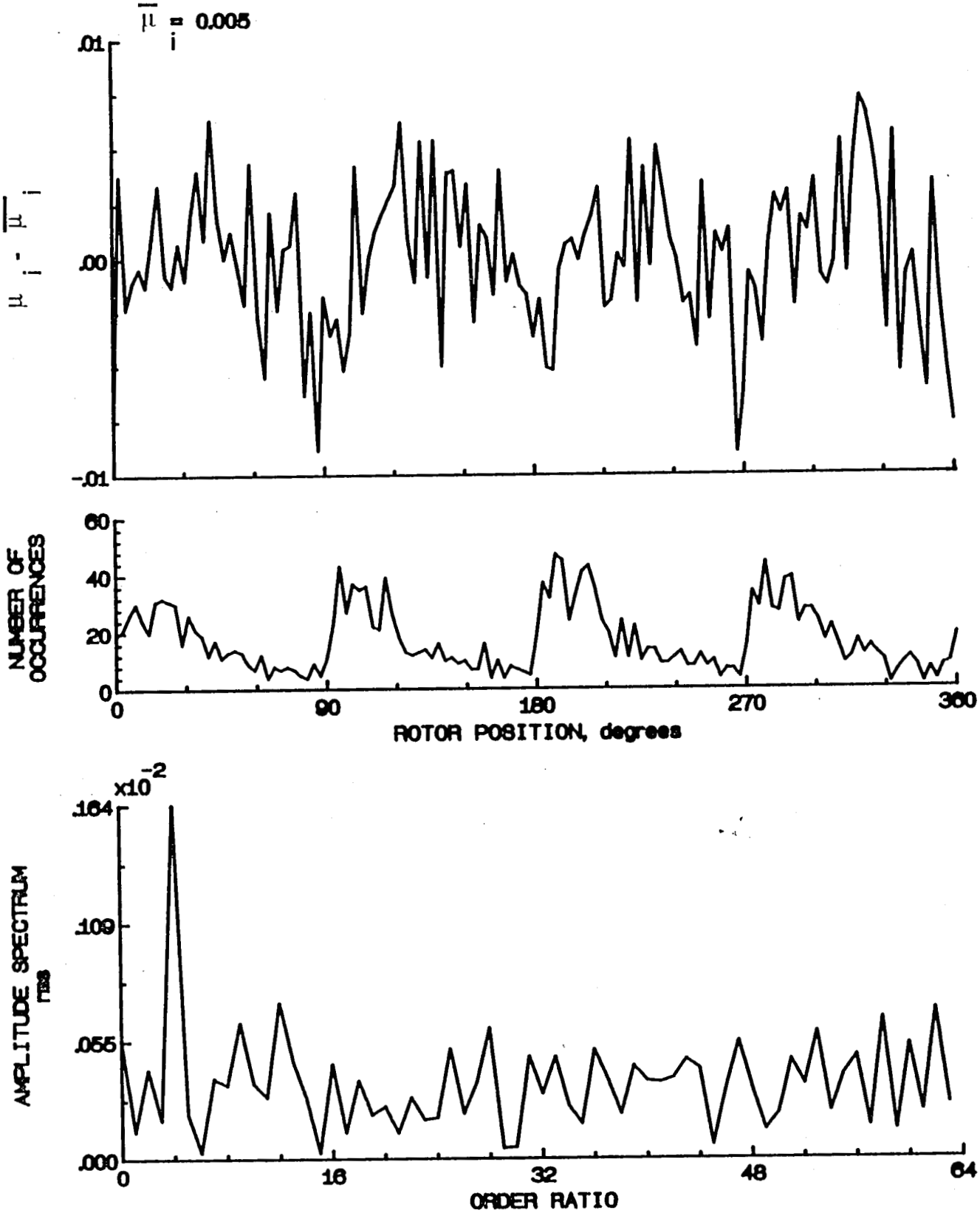


Figure 160.- Induced inflow velocity measured at 270 degrees and r/R of 1.02.

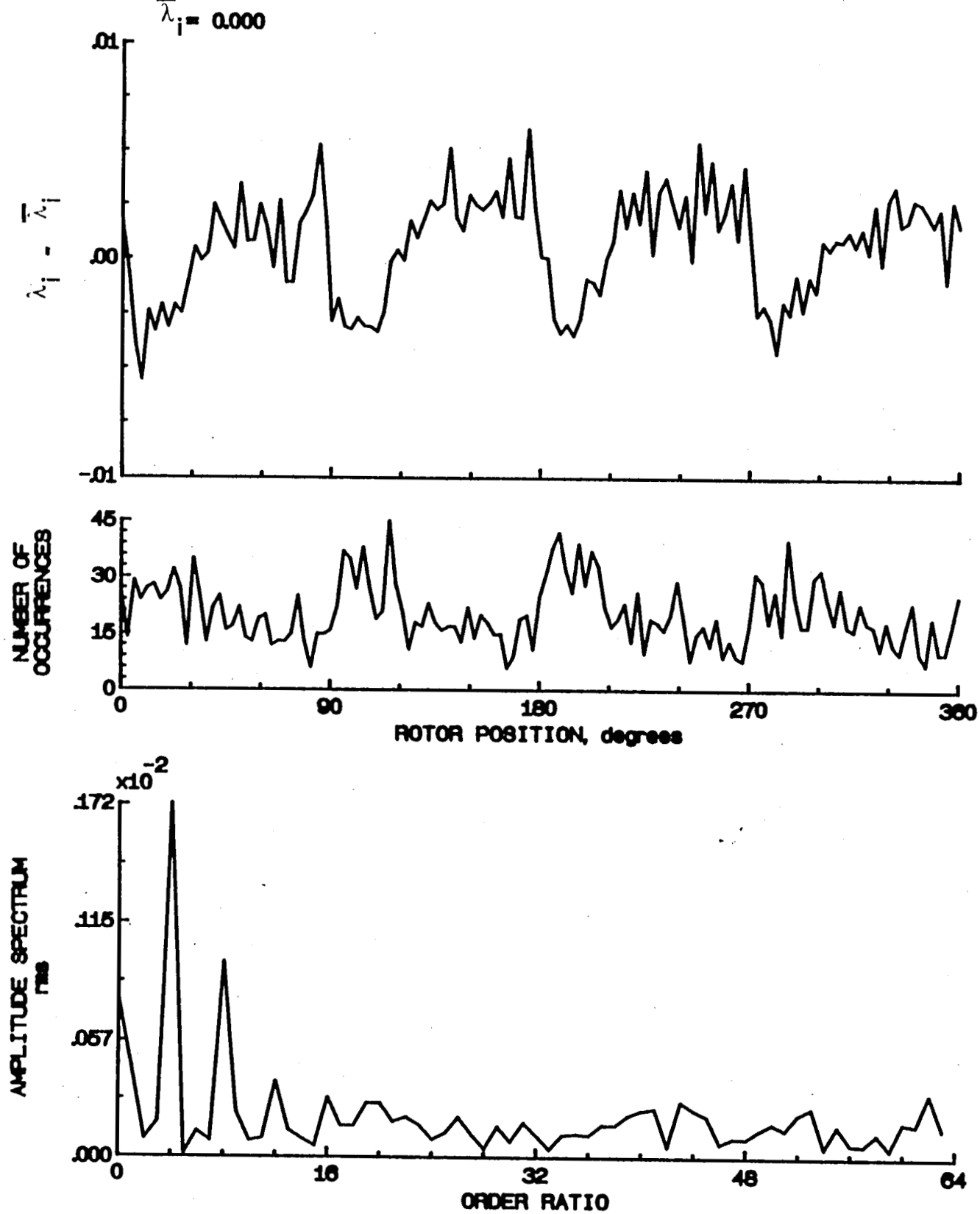


Figure 160.- Concluded.

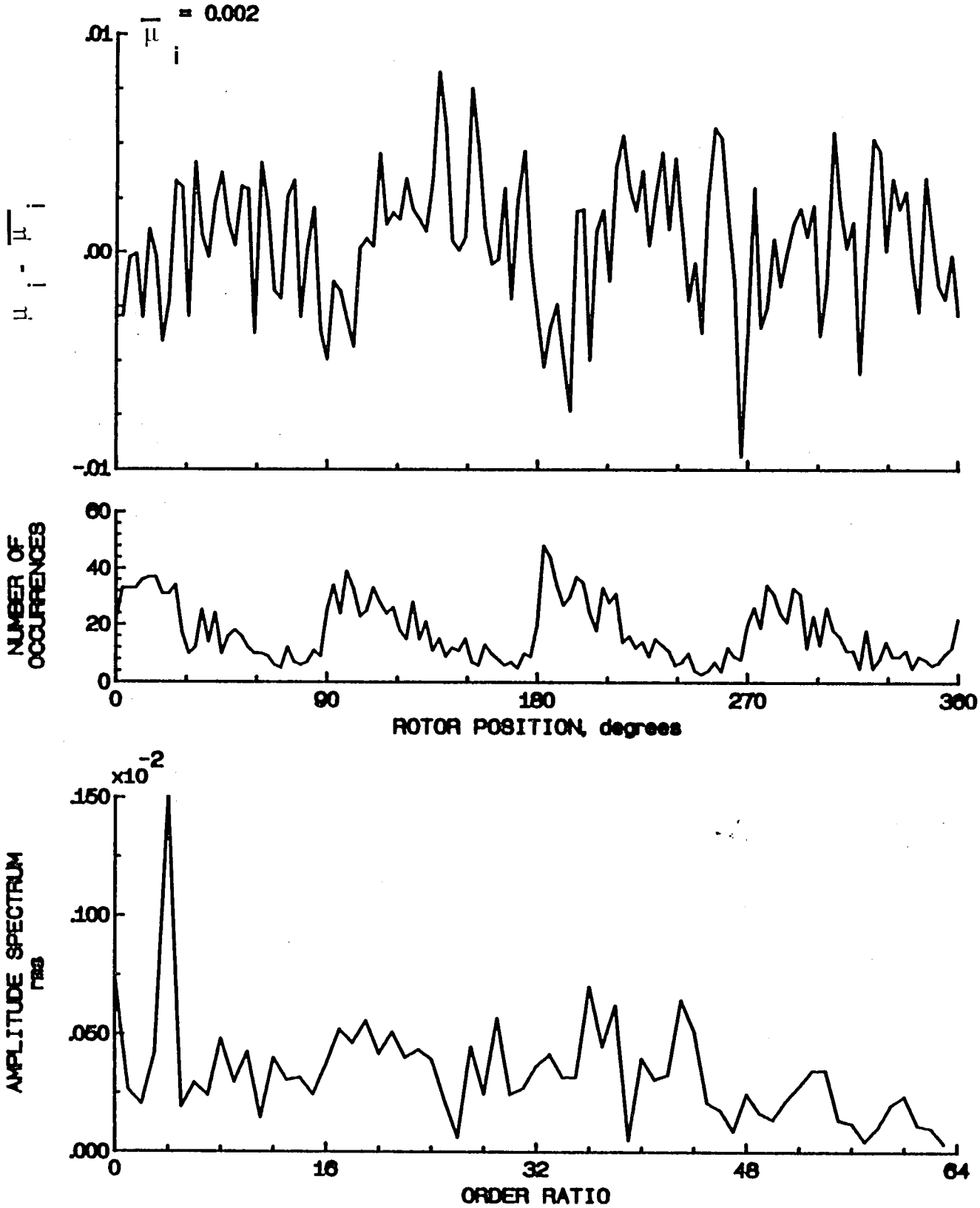
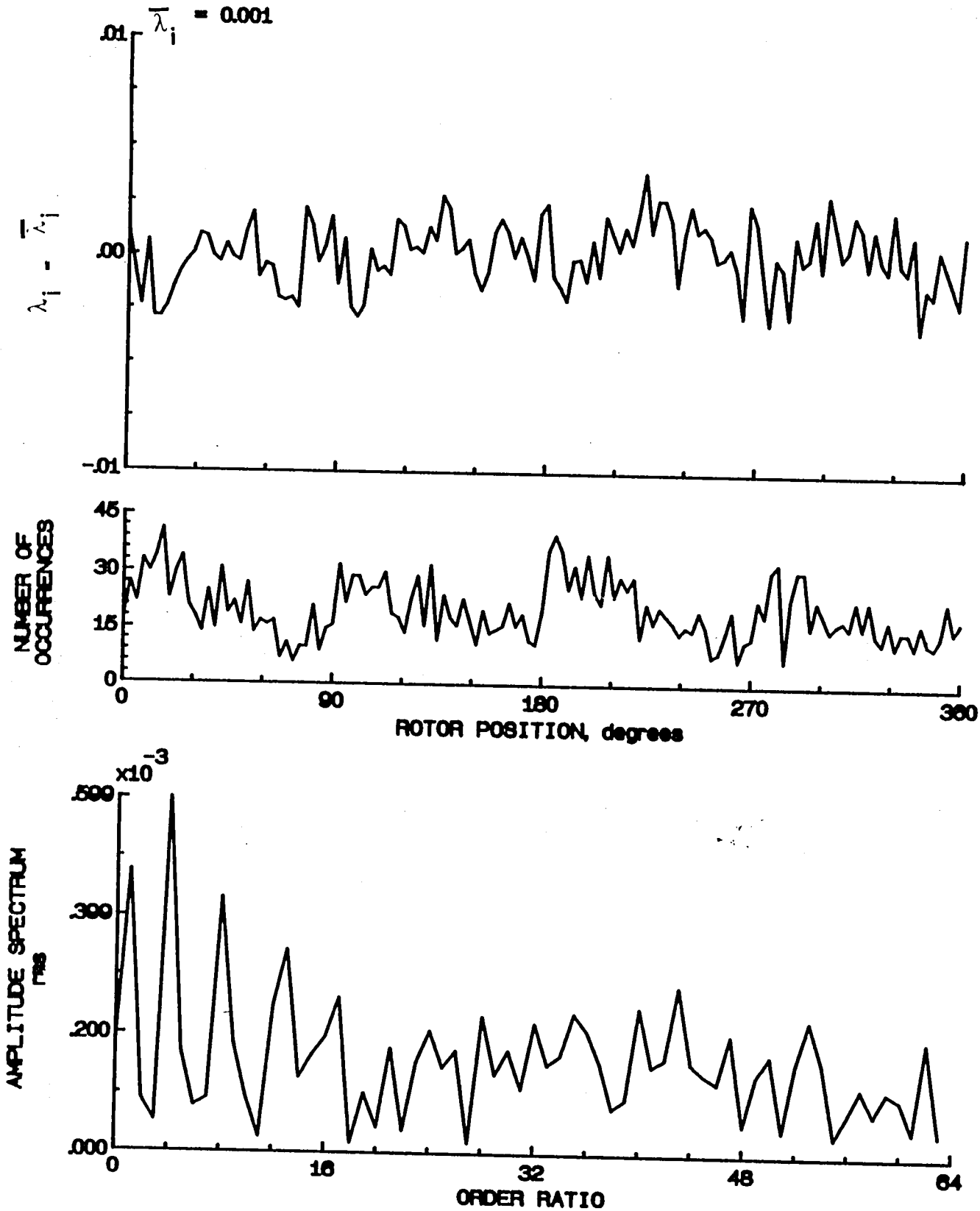


Figure 161.- Induced inflow velocity measured at 270 degrees and r/R of 1.04.



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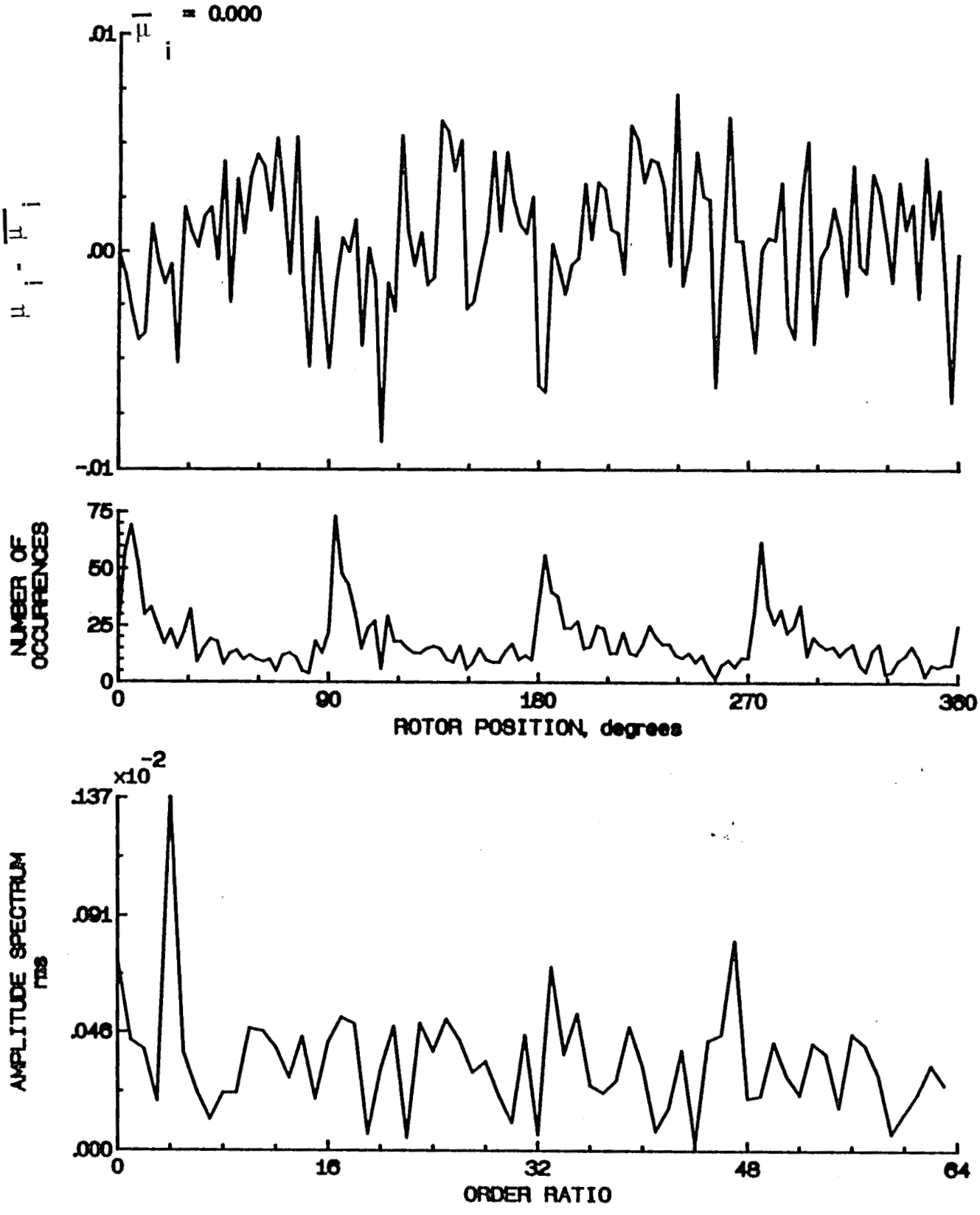


Figure 162.- Induced inflow velocity measured at 270 degrees and r/R of 1.10.

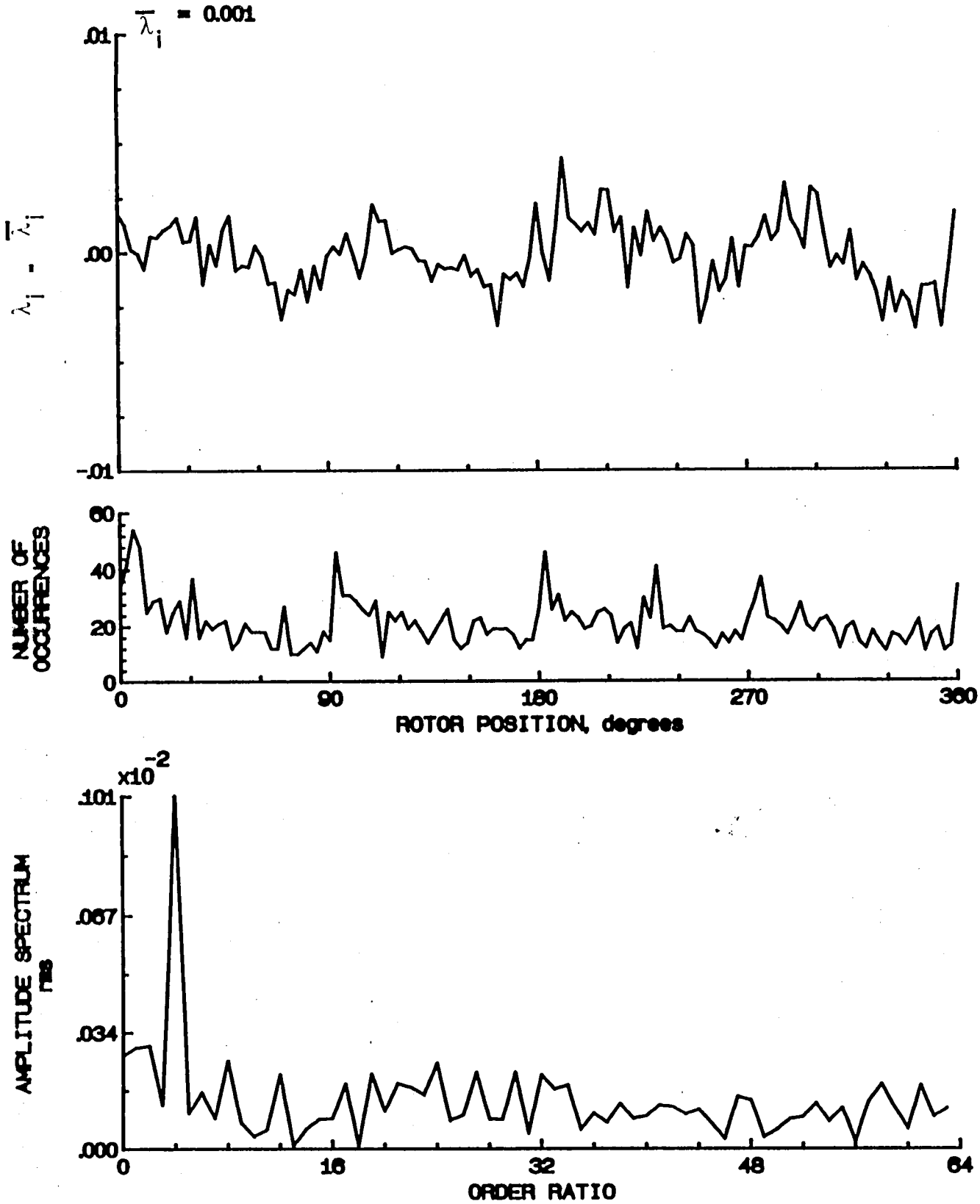


Figure 162.- Concluded.

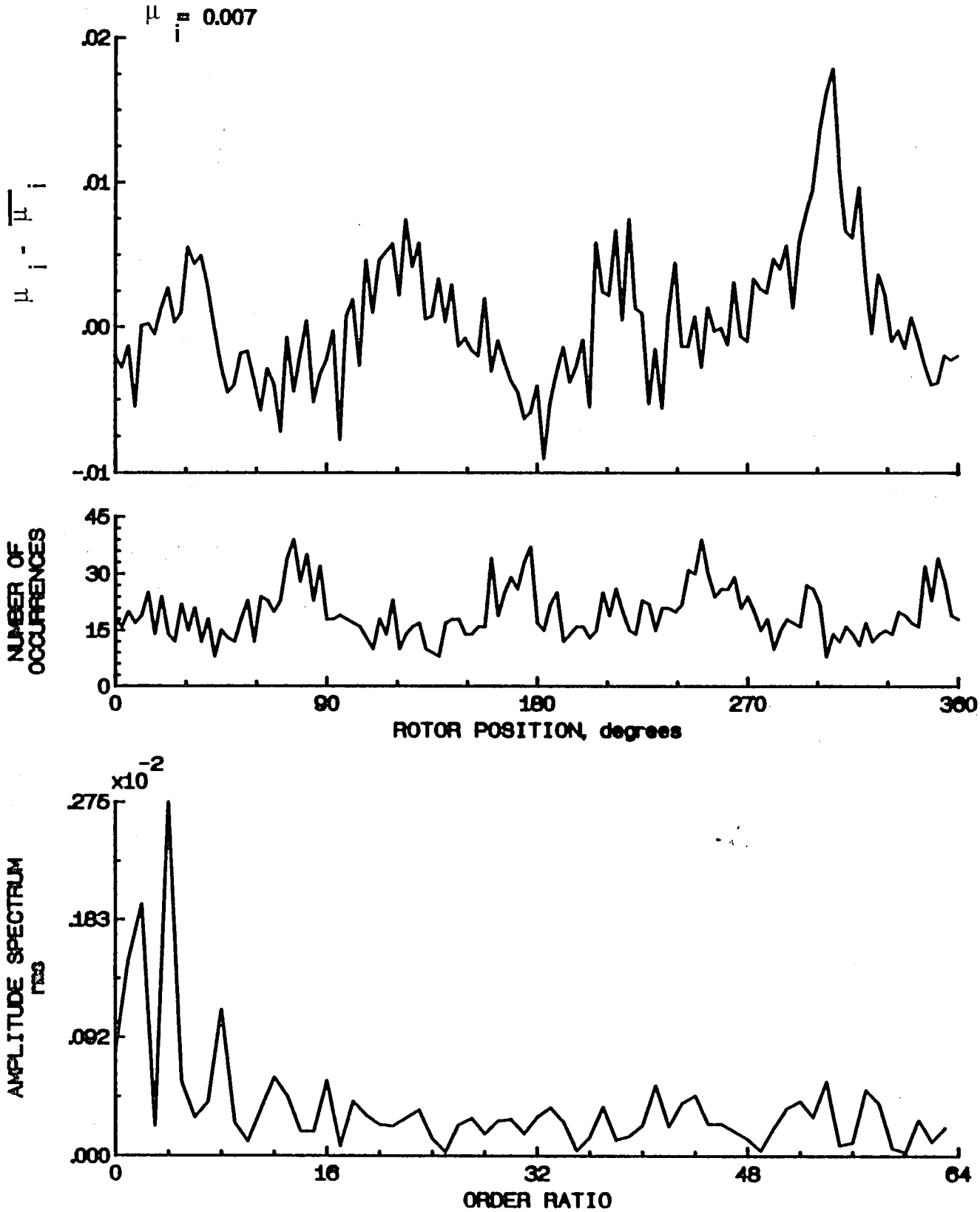


Figure 163.- Induced inflow velocity measured at 300 degrees and r/R of 0.20.

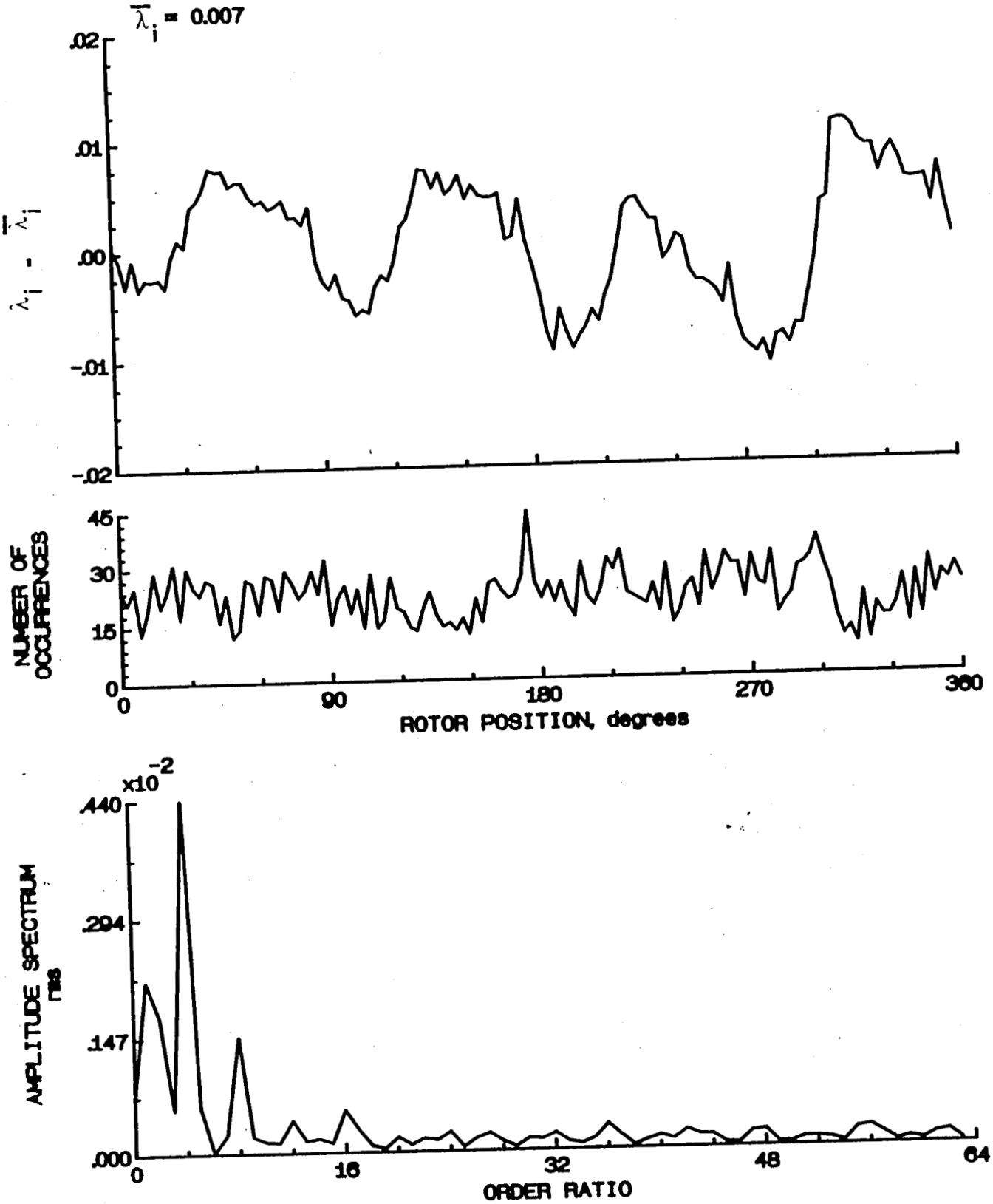


Figure 163.- Concluded.

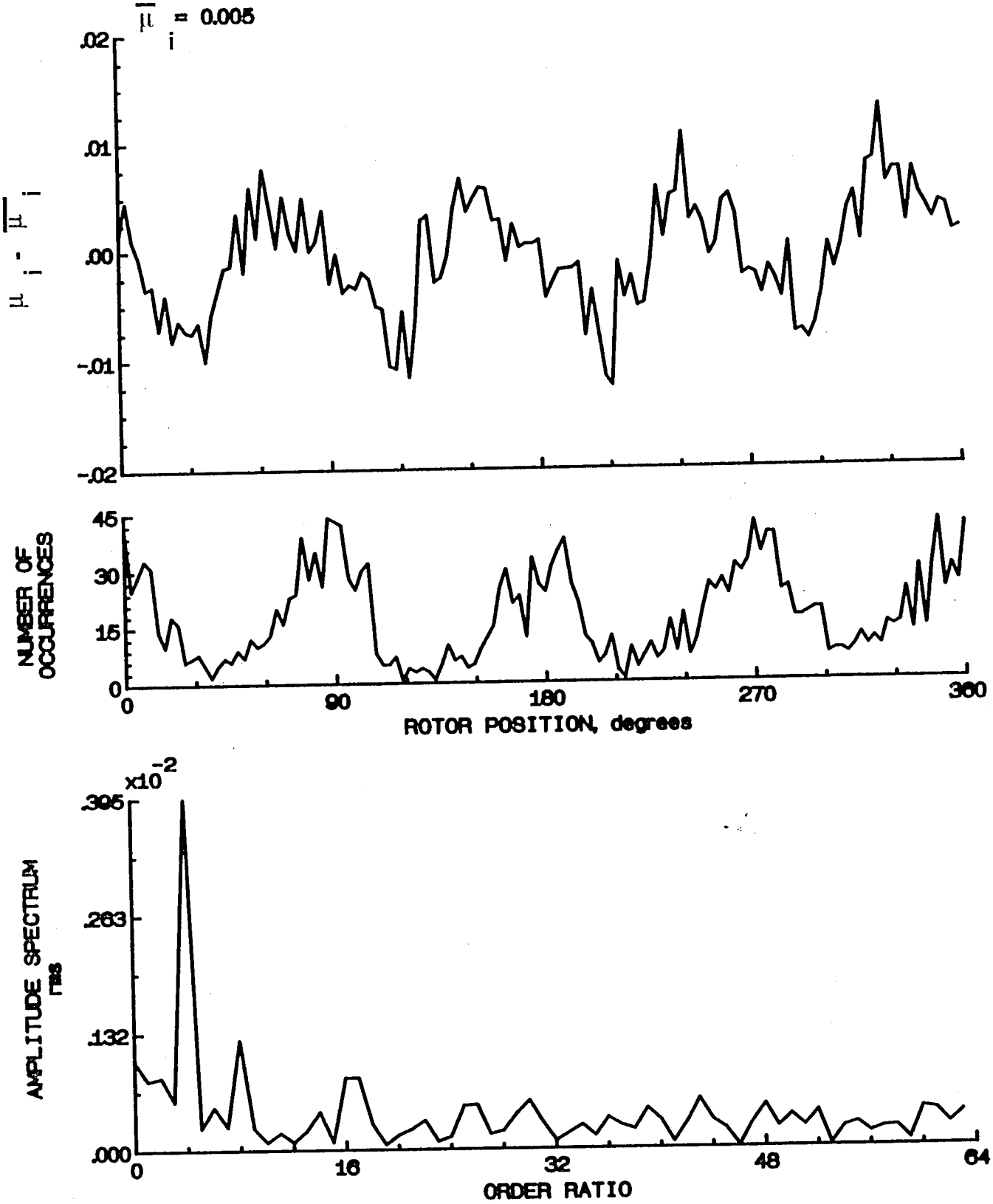


Figure 164.- Induced inflow velocity measured at 300 degrees and r/R of 0.40.

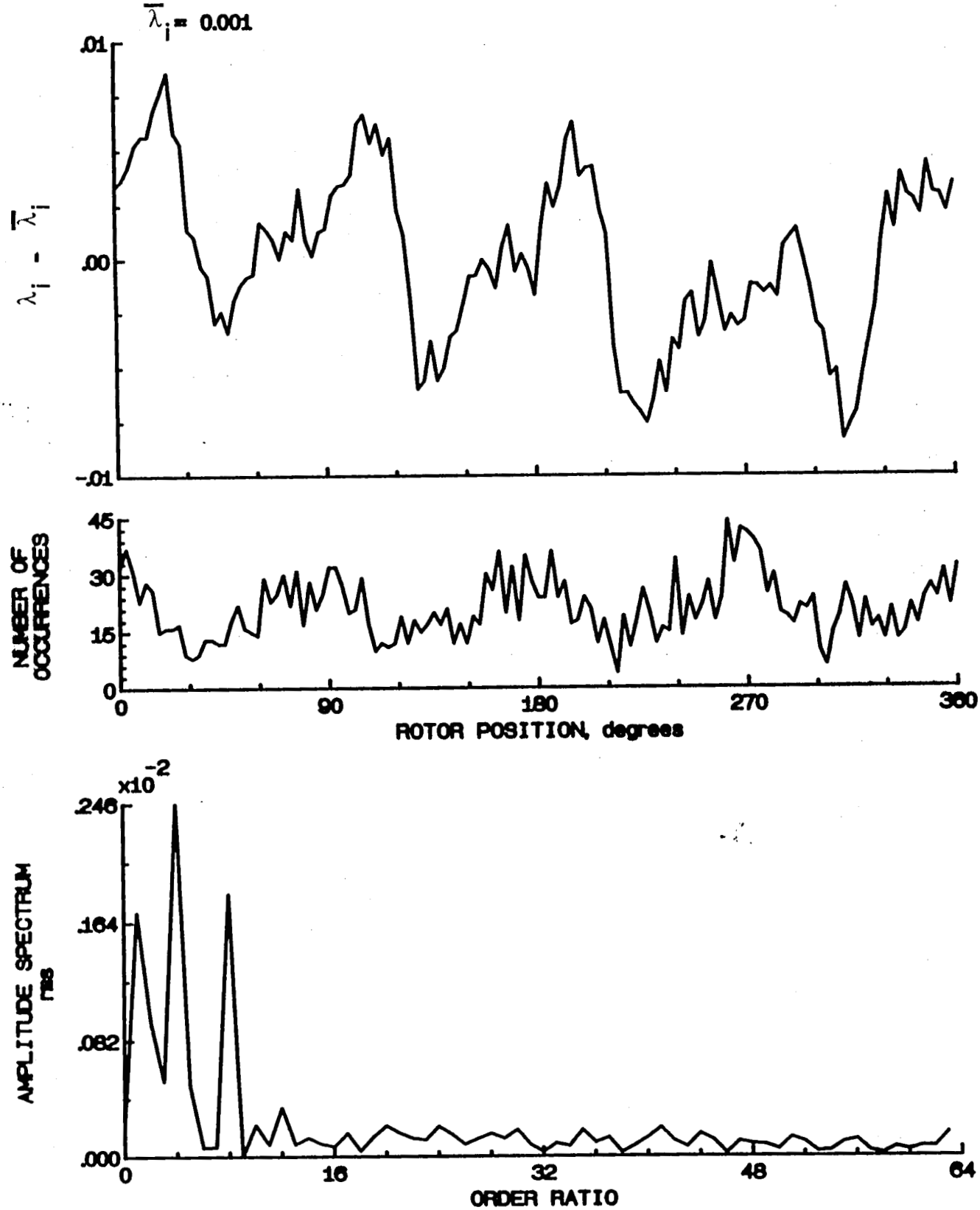


Figure 164.- Concluded.

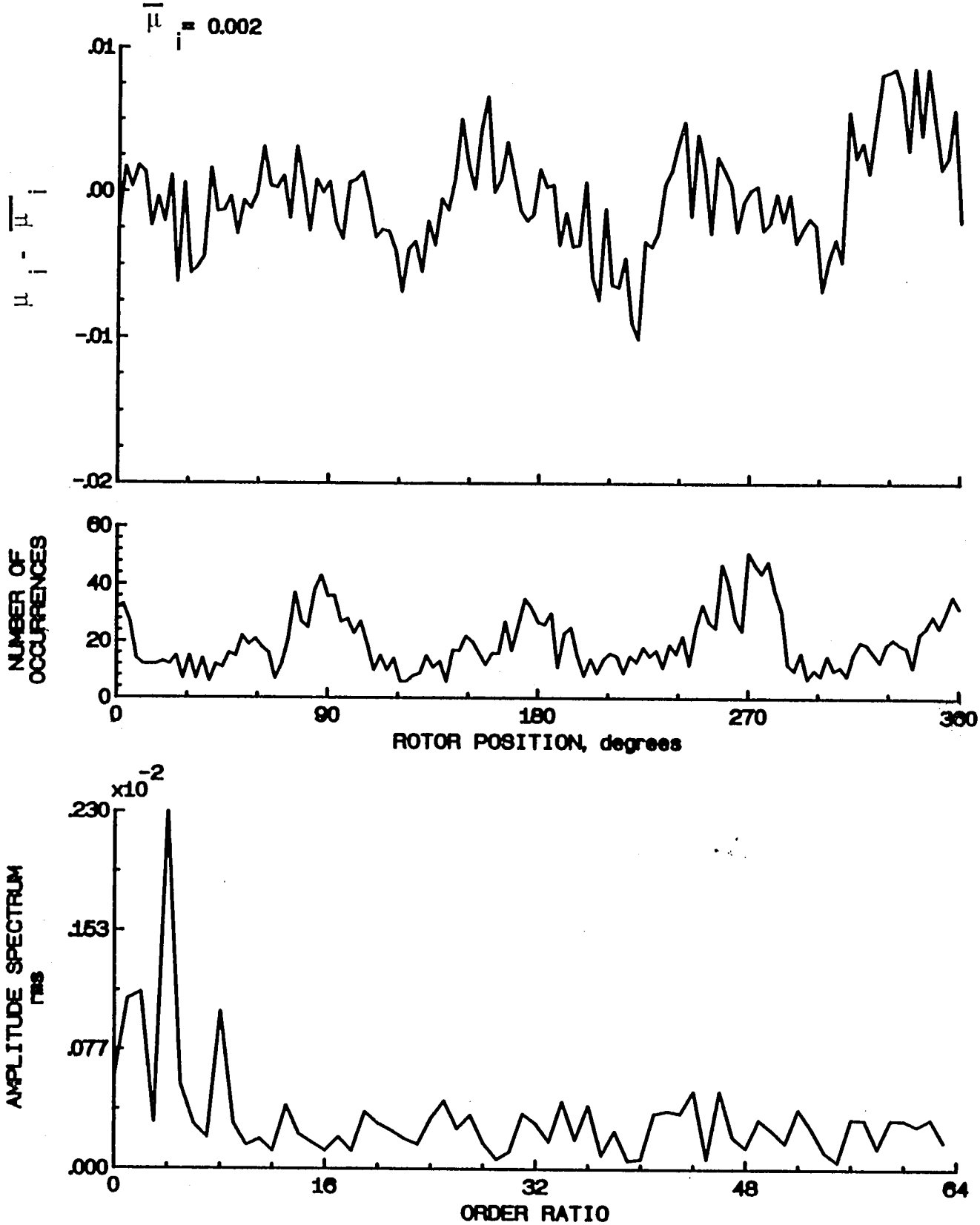


Figure 165.- Induced inflow velocity measured at 300 degrees and r/R of 0.50.

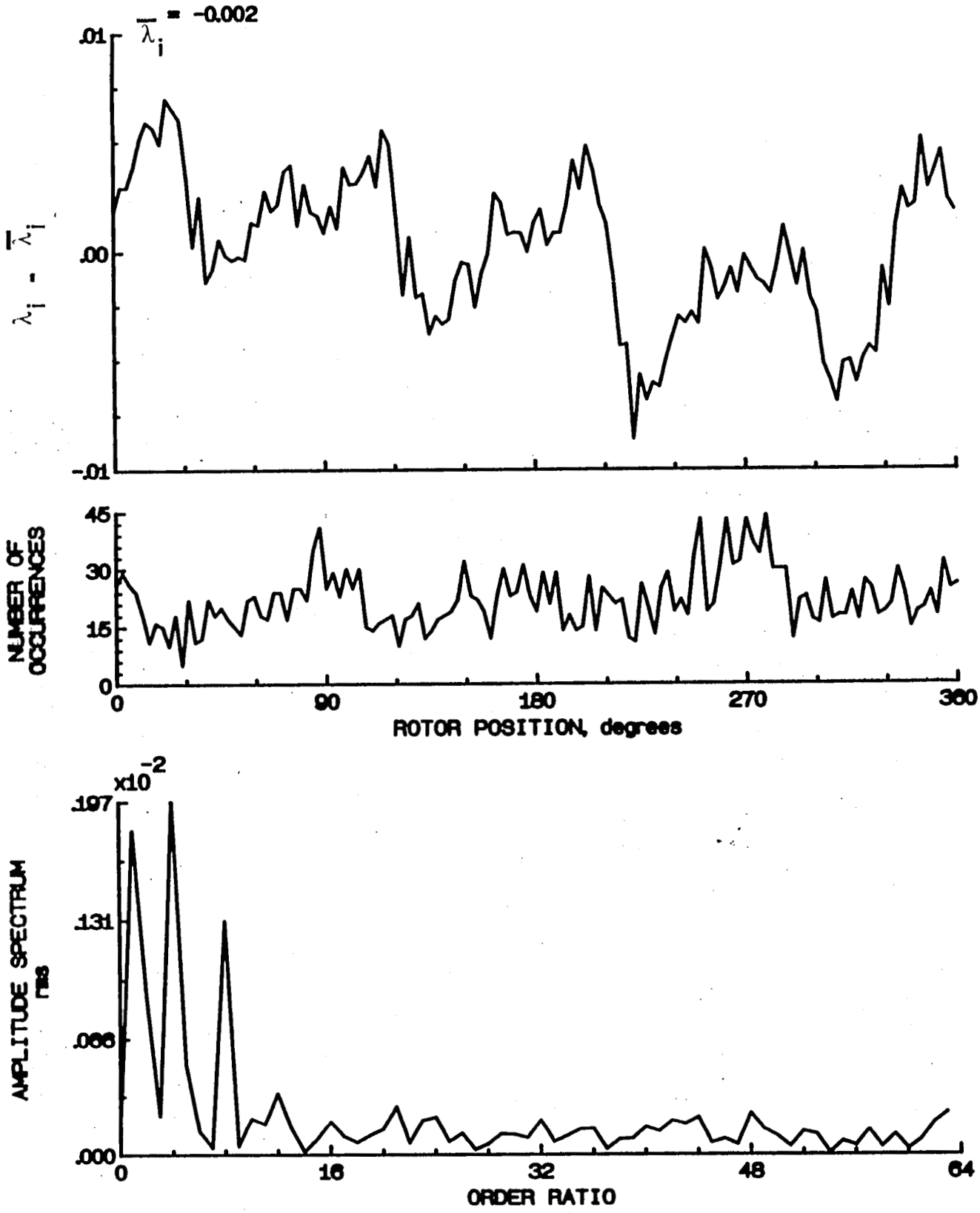


Figure 165.- Concluded.

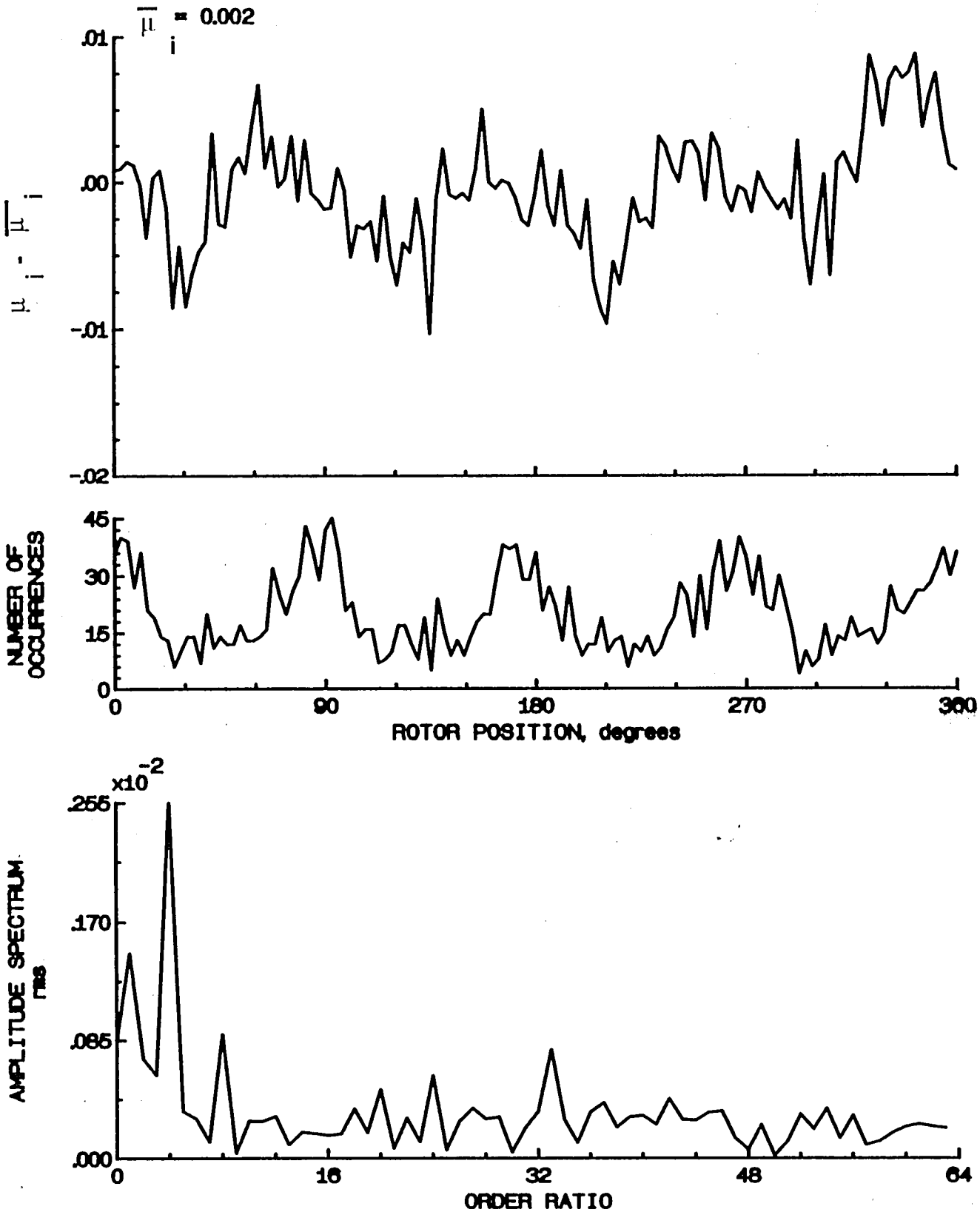


Figure 166.- Induced inflow velocity measured at 300 degrees and r/R of 0.60.

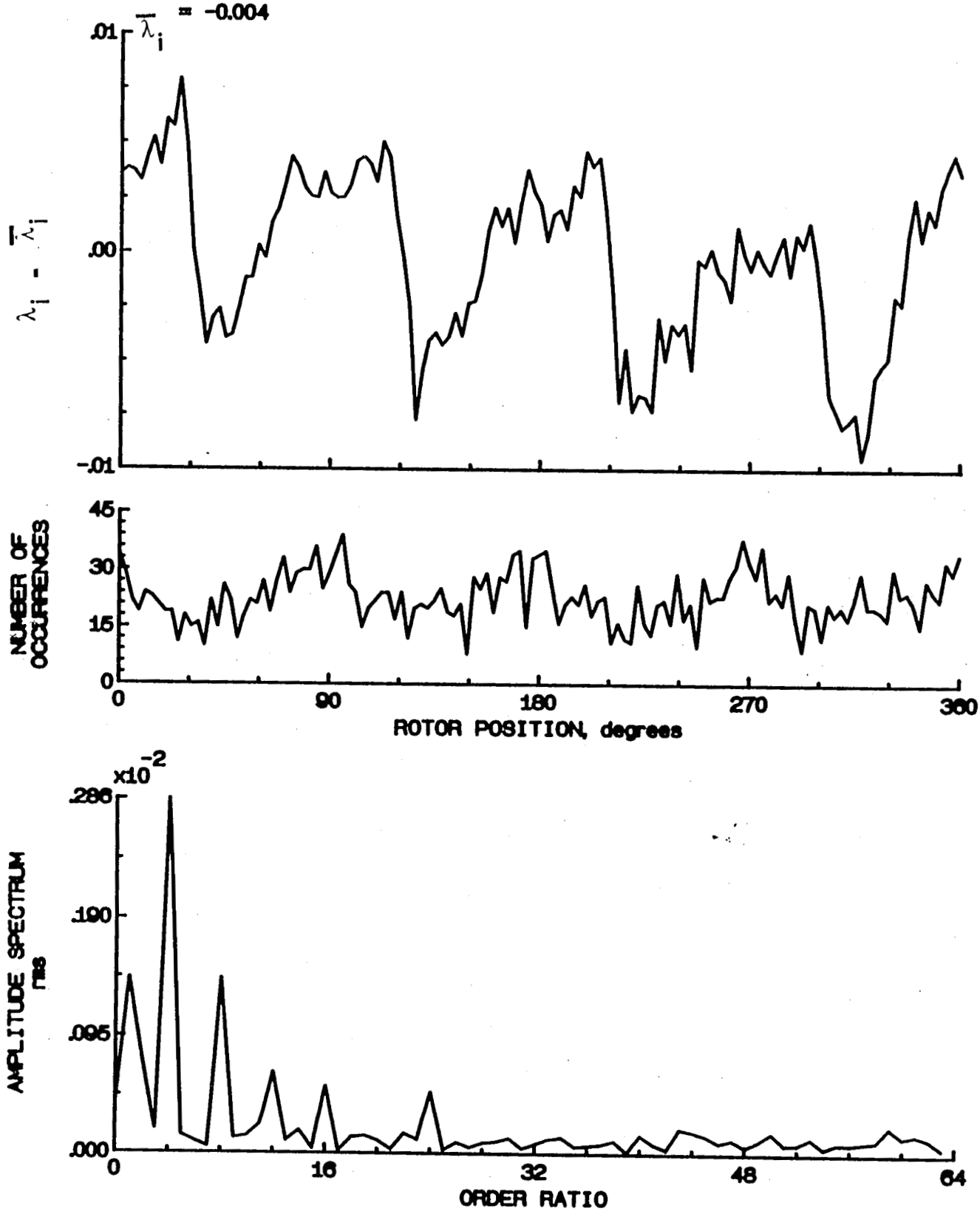


Figure 166.- Concluded.

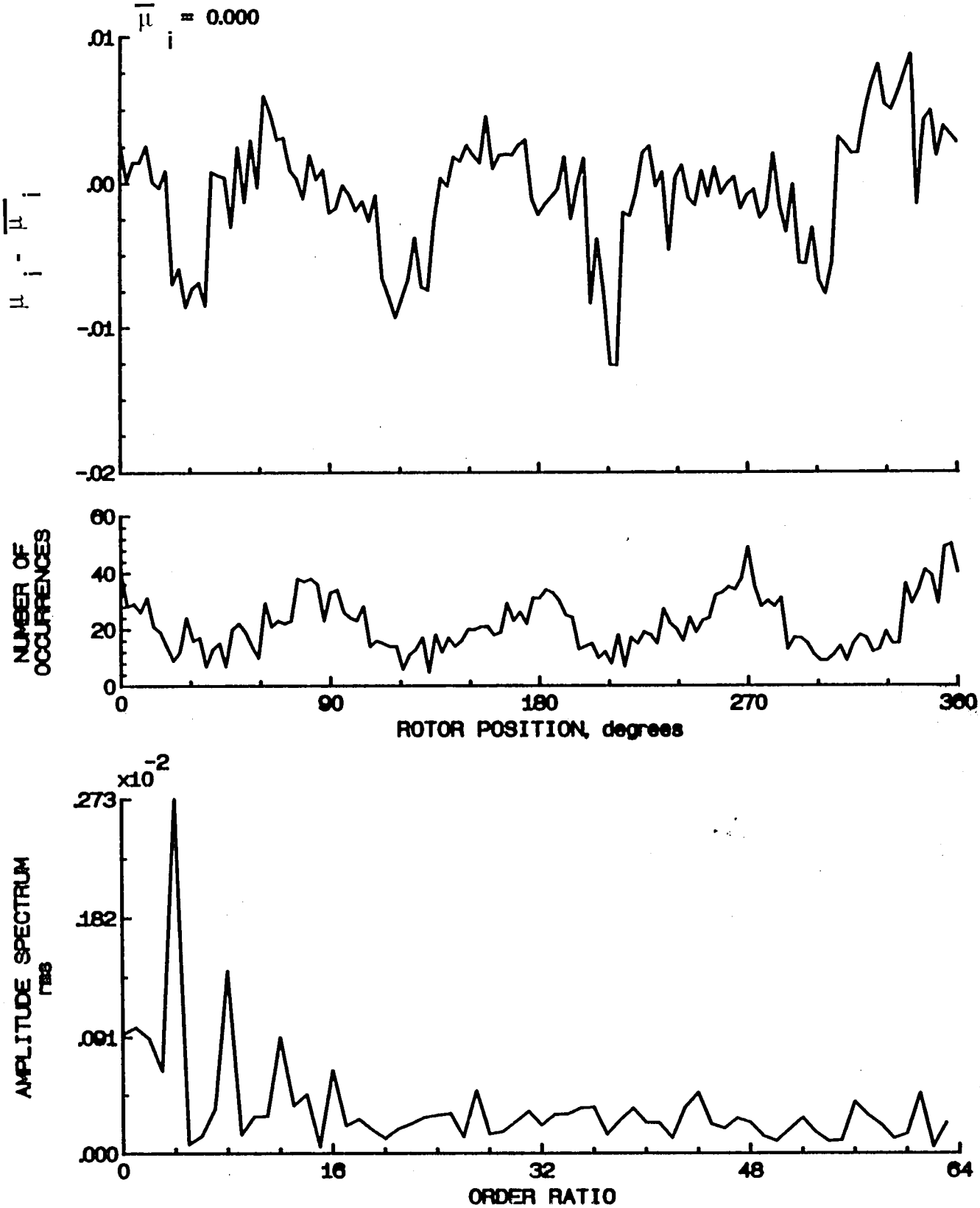


Figure 167.- Induced inflow velocity measured at 300 degrees and r/R of 0.70.

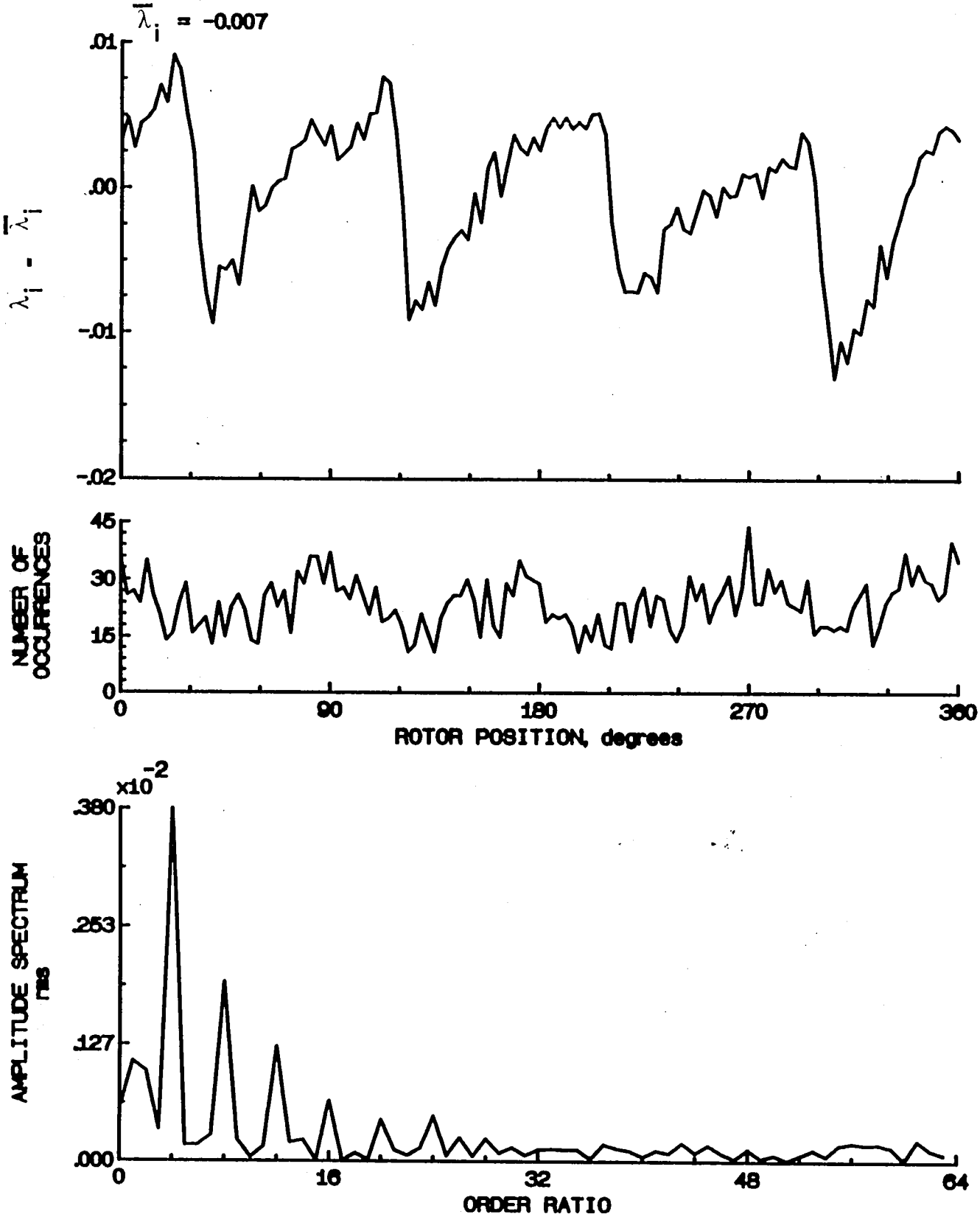


Figure 167.- Concluded.

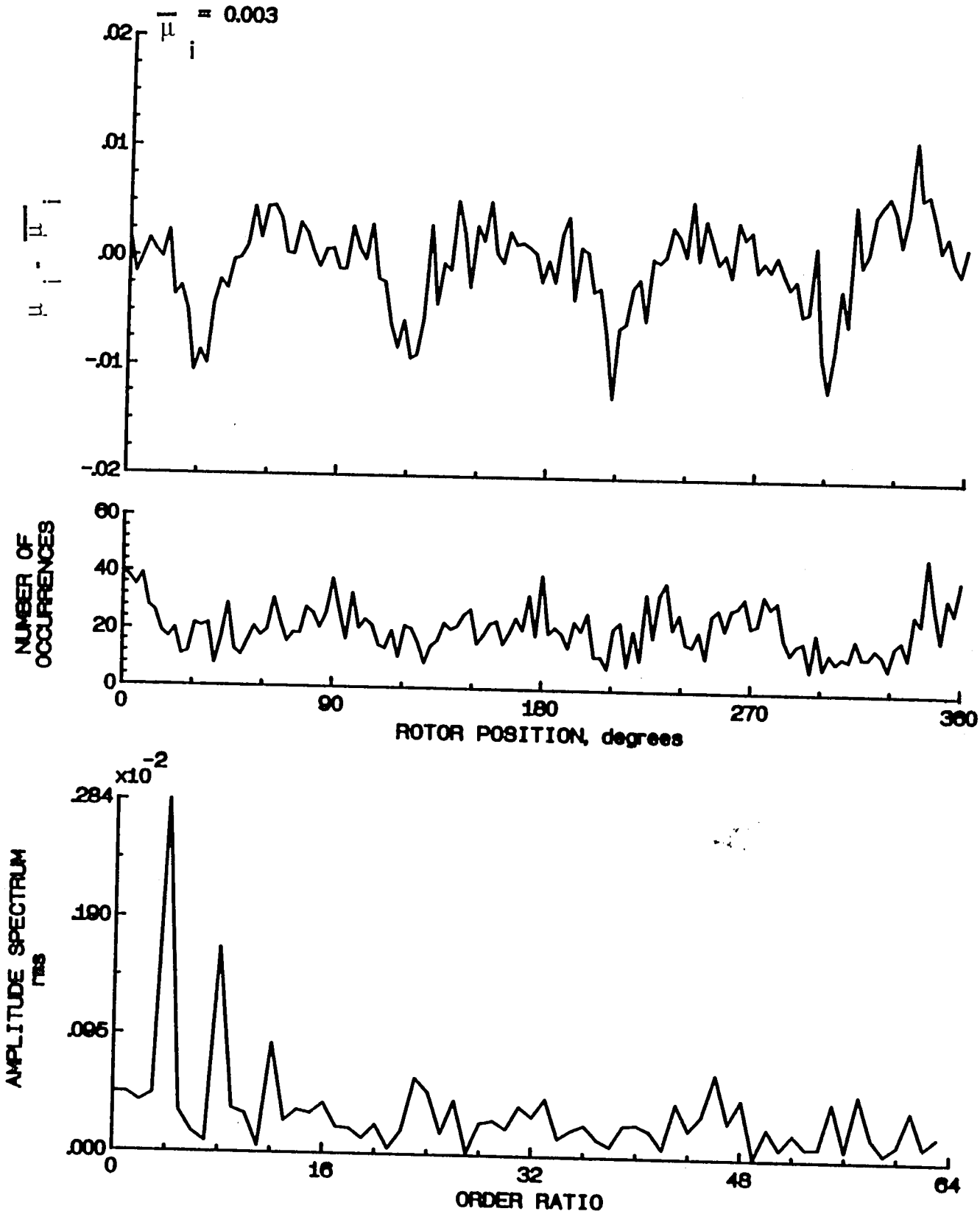
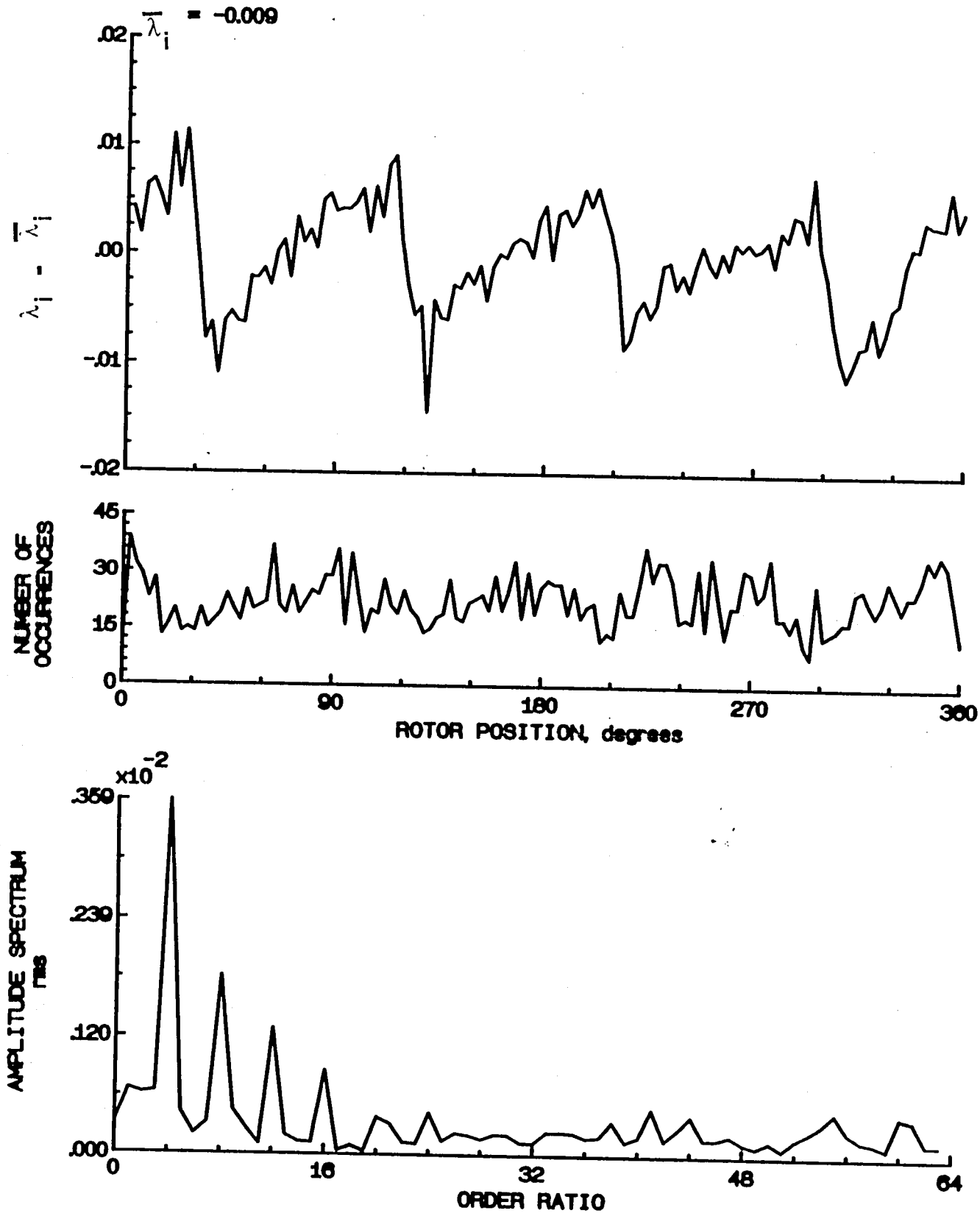


Figure 168.- Induced inflow velocity measured at 300 degrees and r/R of 0.74.



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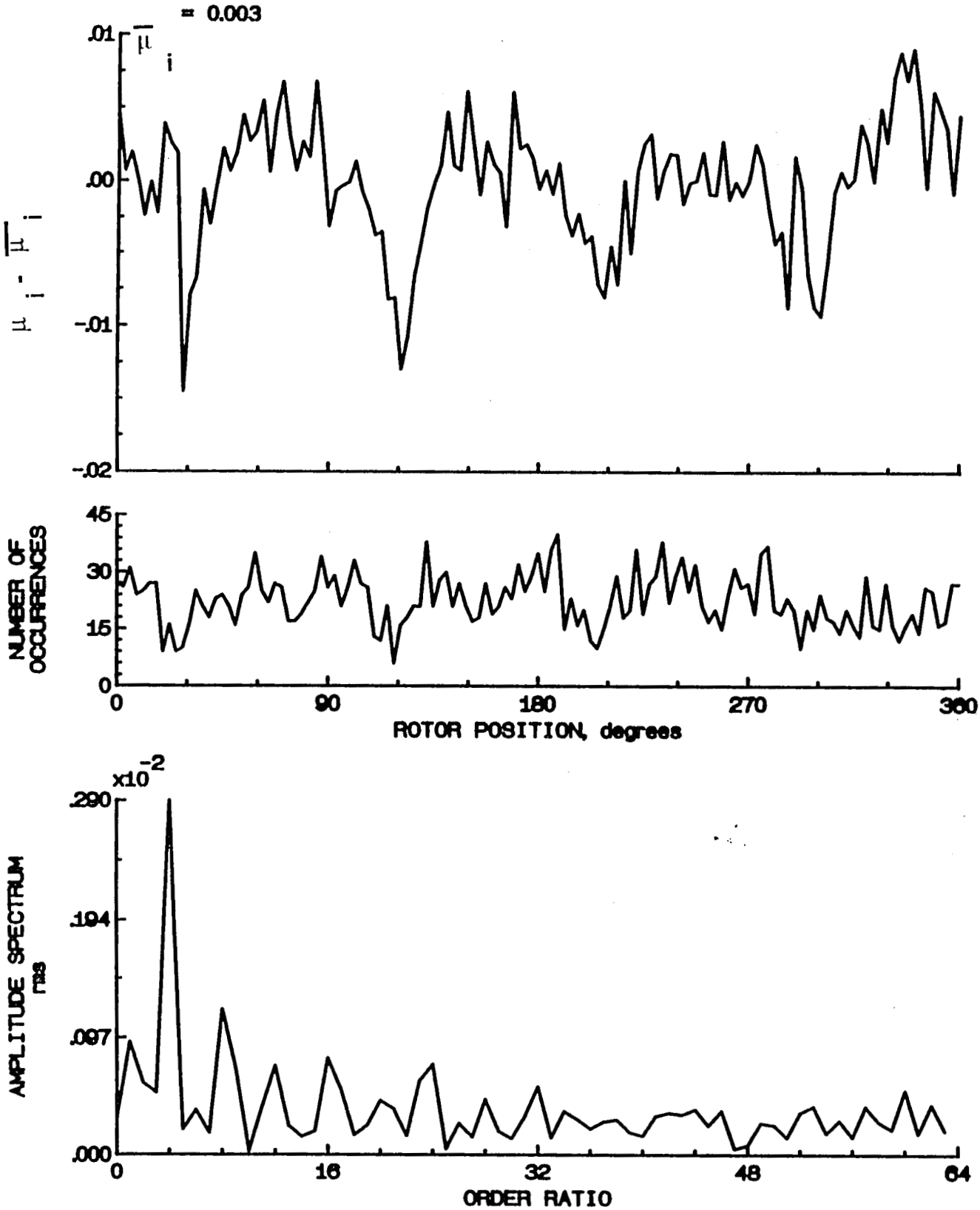
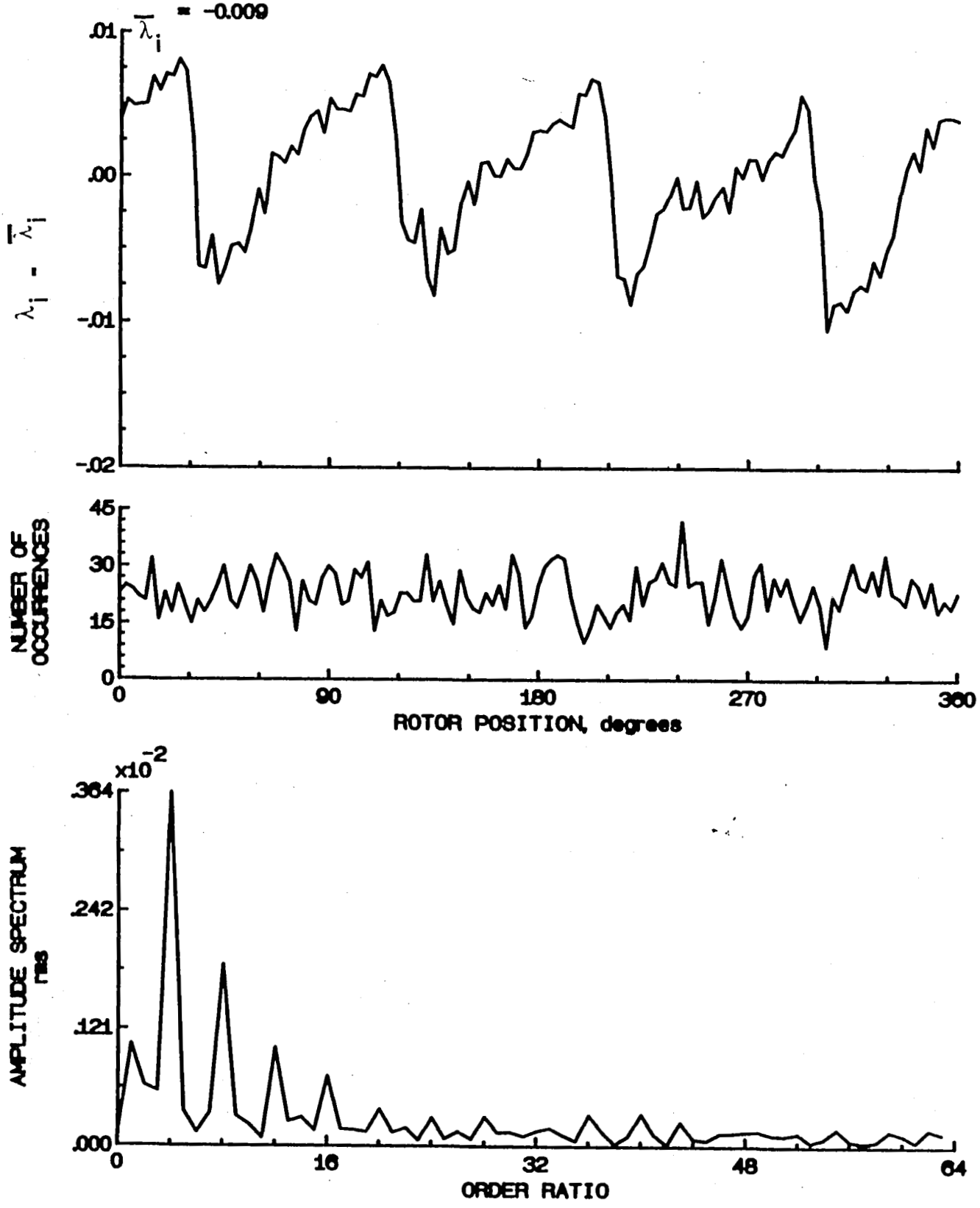


Figure 169.- Induced inflow velocity measured at 300 degrees and r/R of 0.78.



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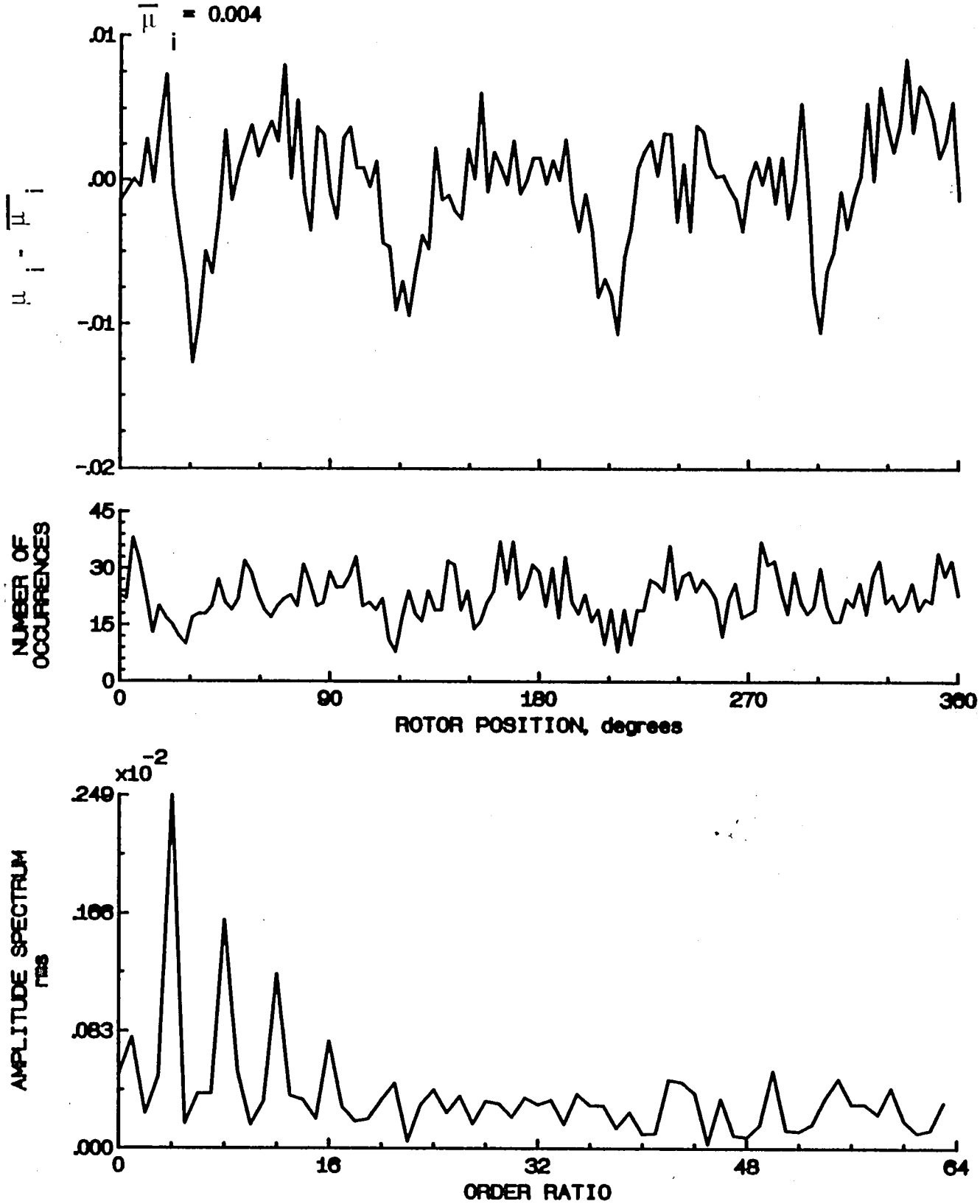
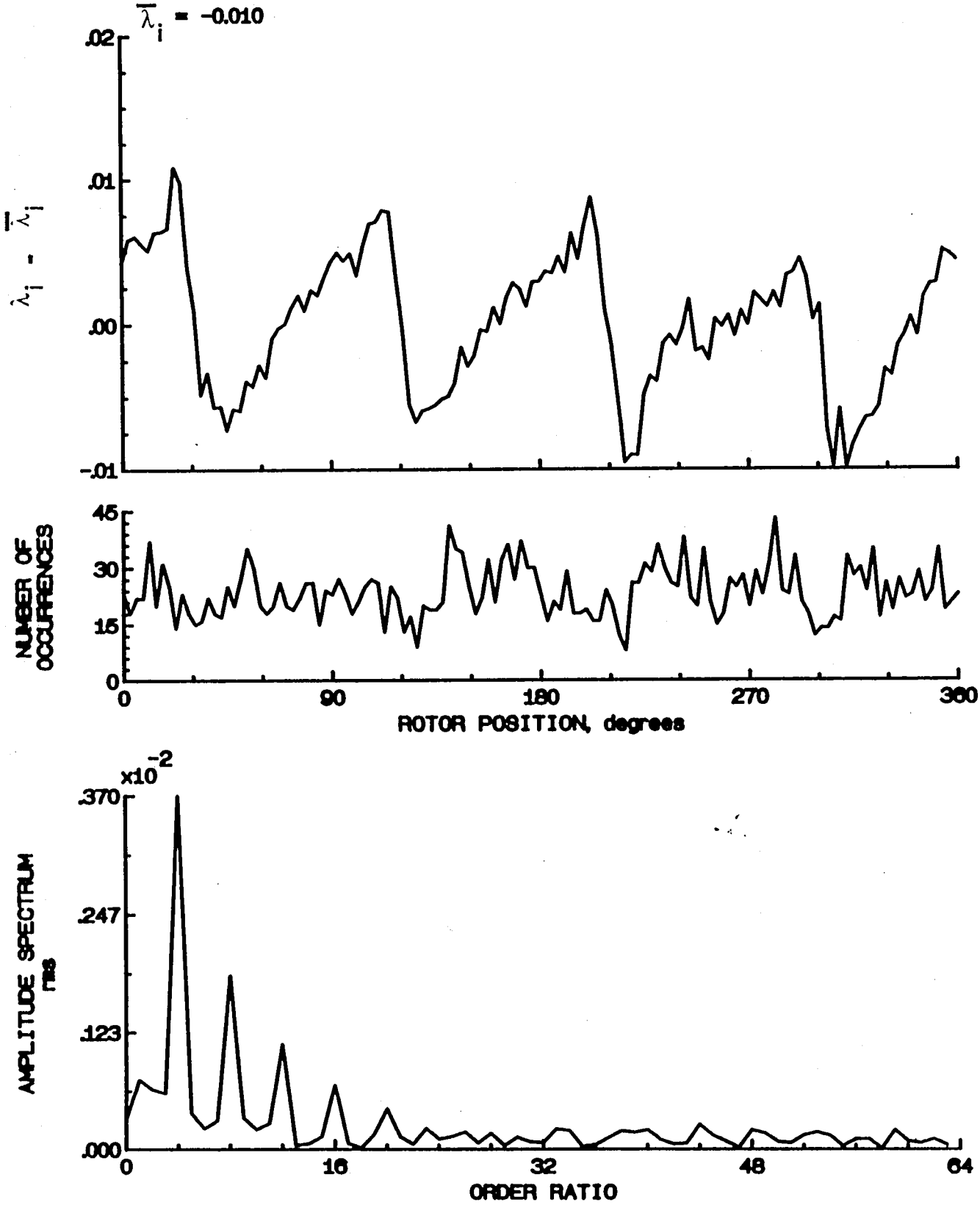


Figure 170.- Induced inflow velocity measured at 300 degrees and r/R of 0.82.



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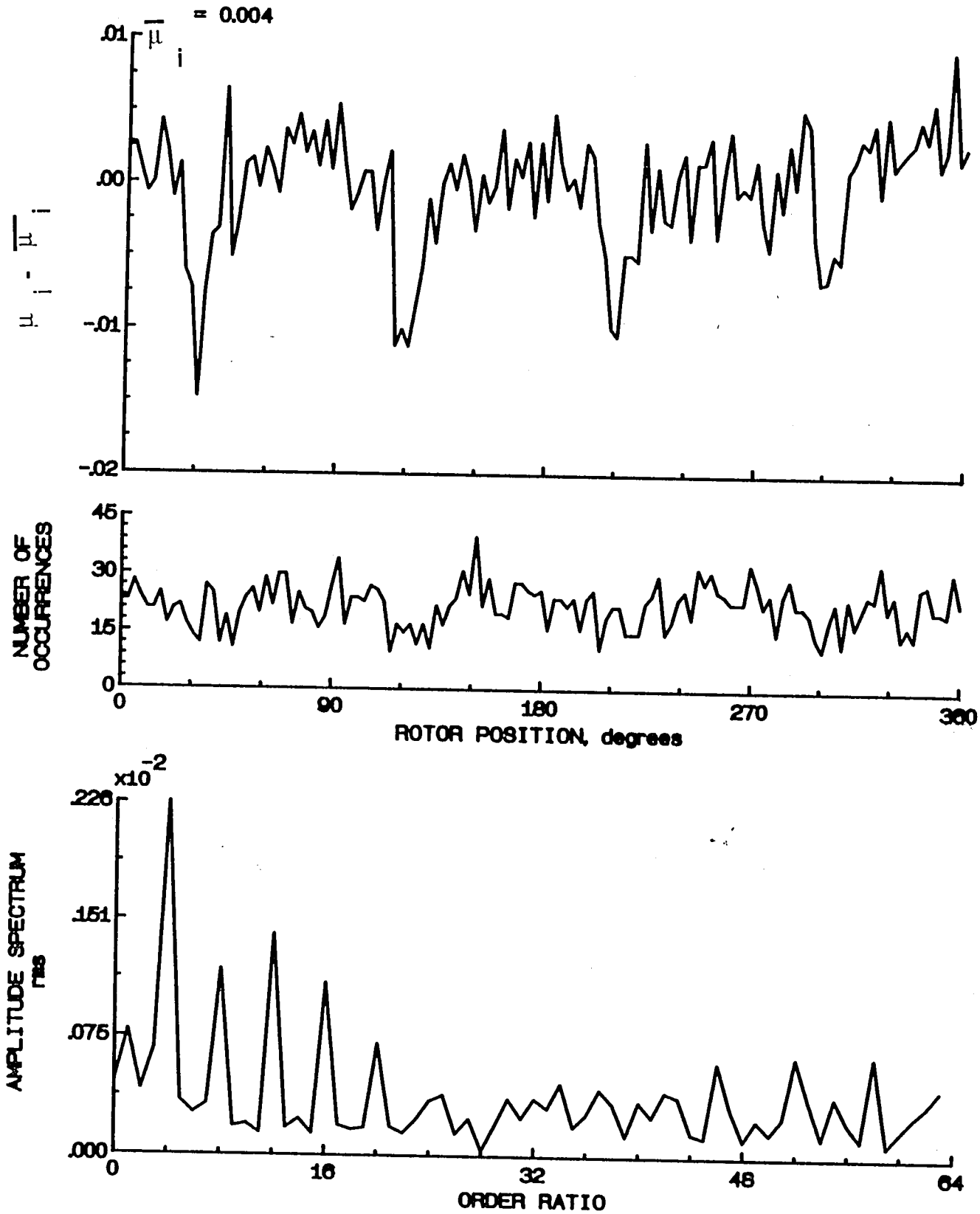
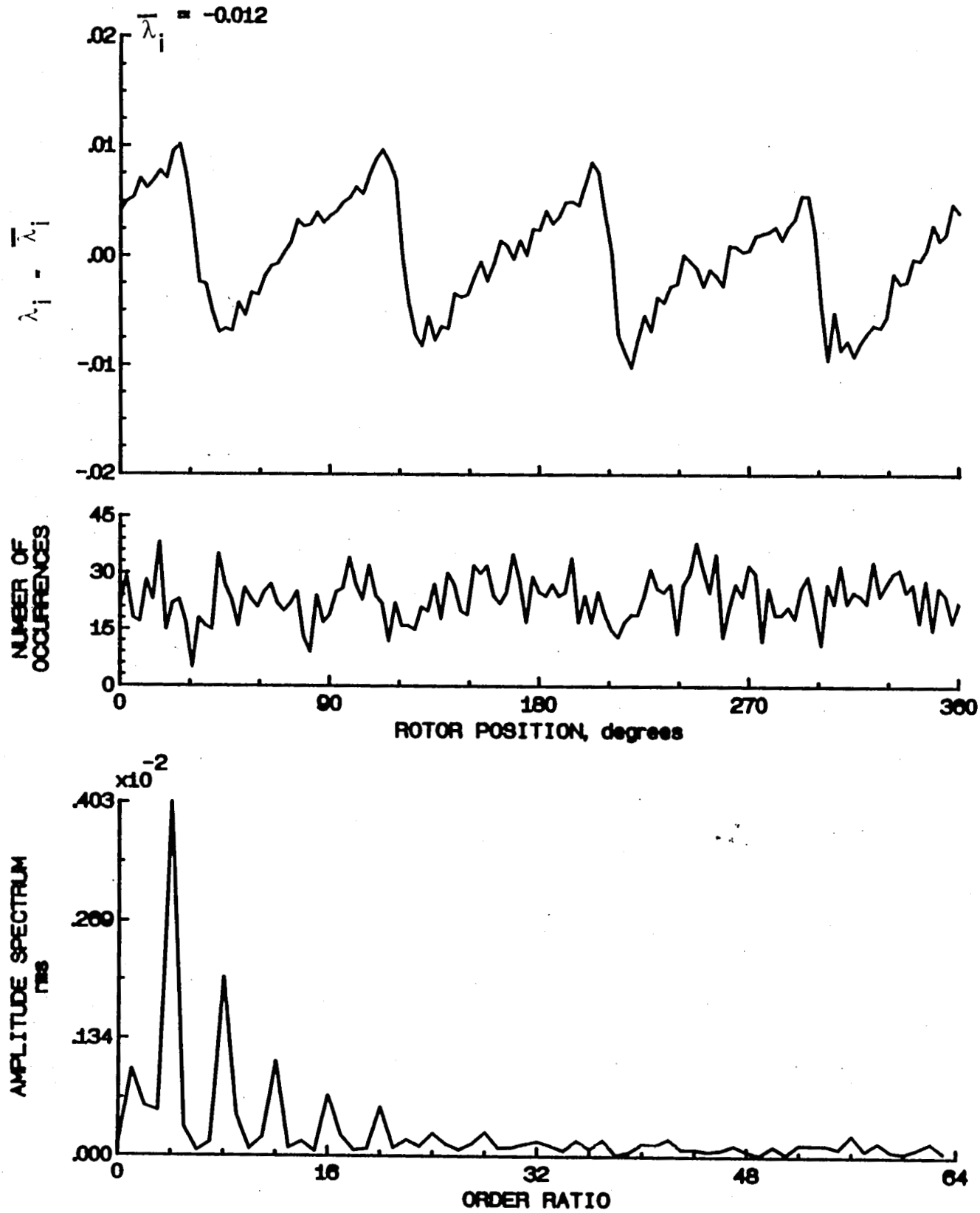


Figure 171.- Induced inflow velocity measured at 300 degrees and r/R of 0.86.



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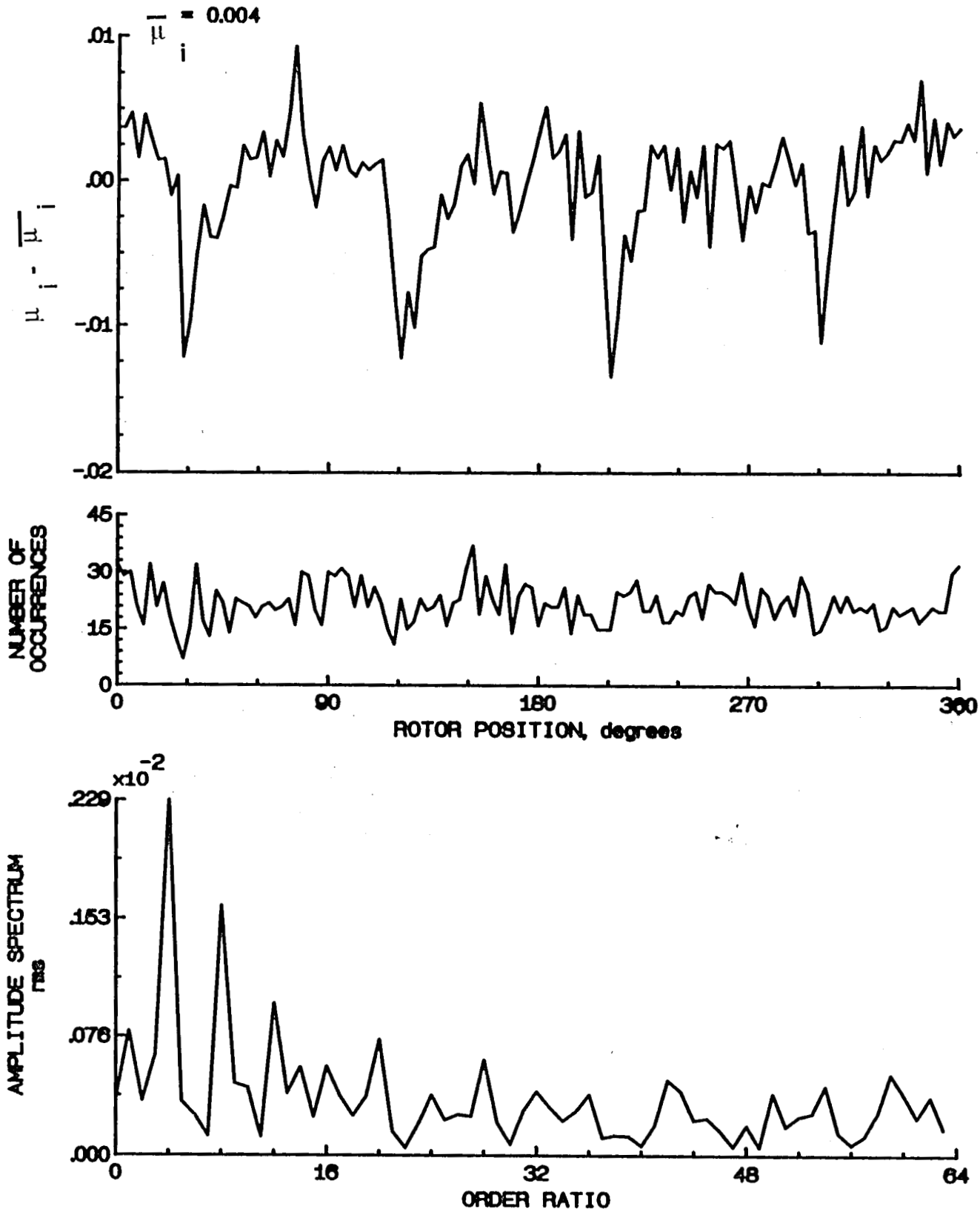
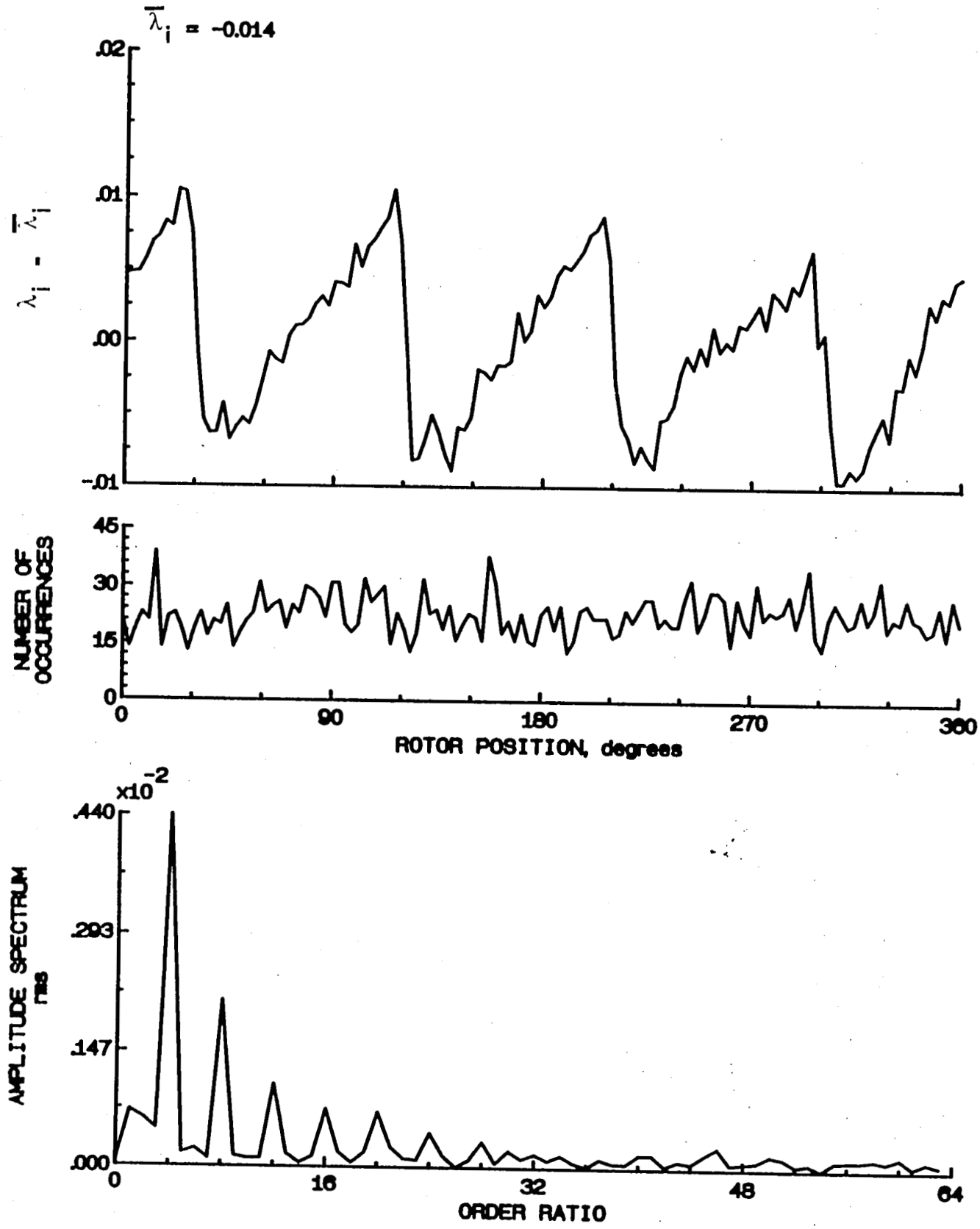


Figure 172.- Induced inflow velocity measured at 300 degrees and r/R of 0.90.



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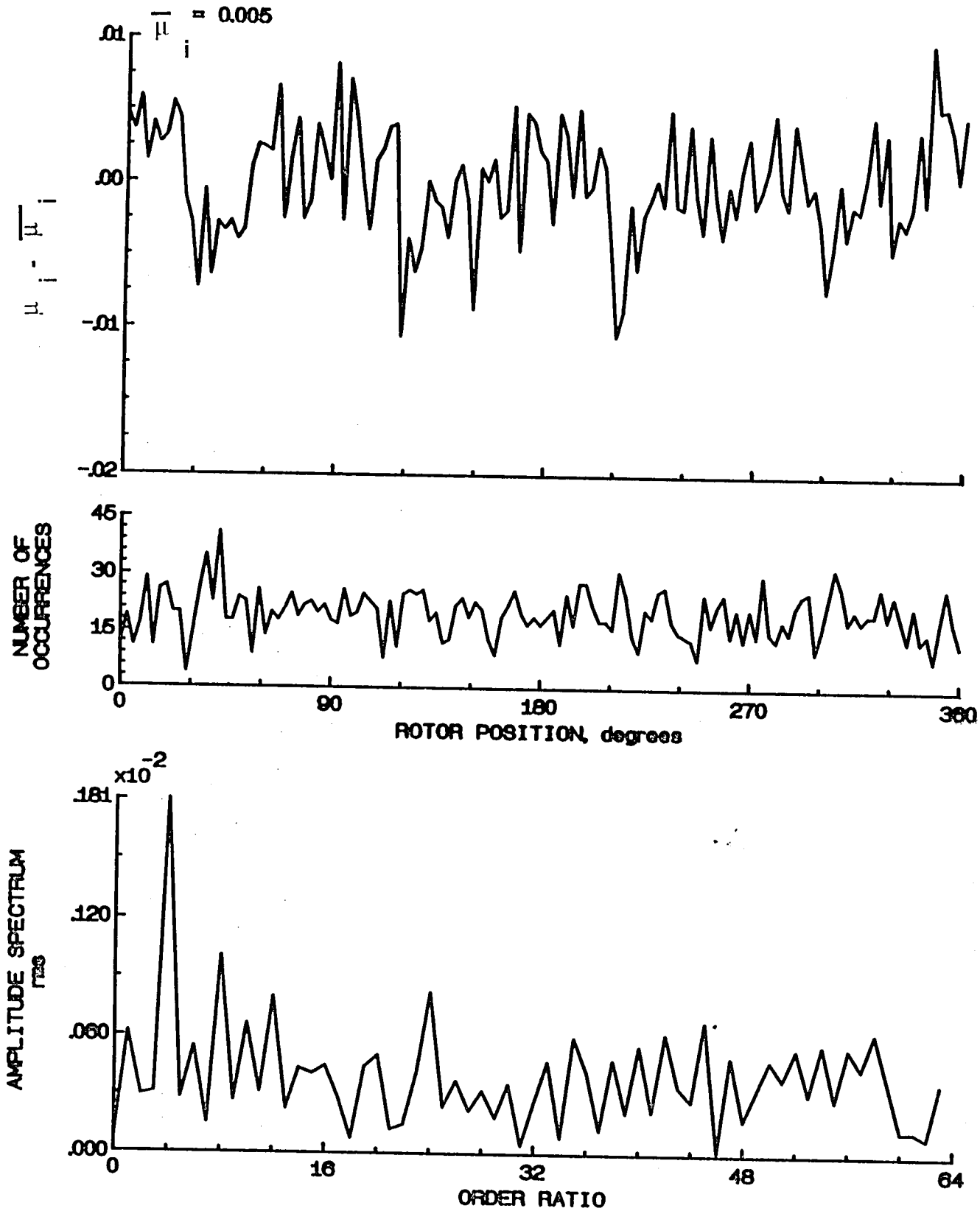
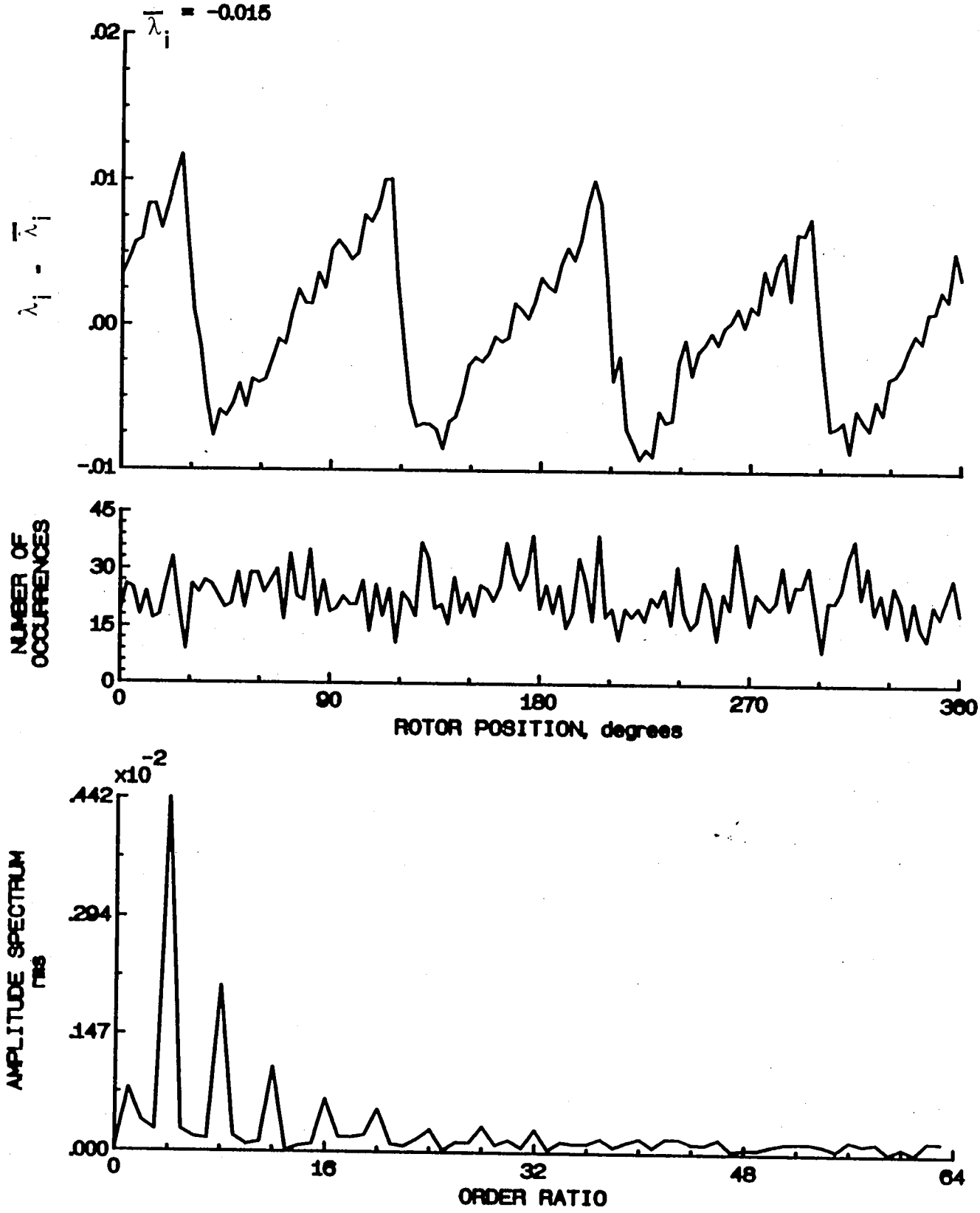


Figure 173.- Induced inflow velocity measured at 300 degrees and r/R of 0.94.



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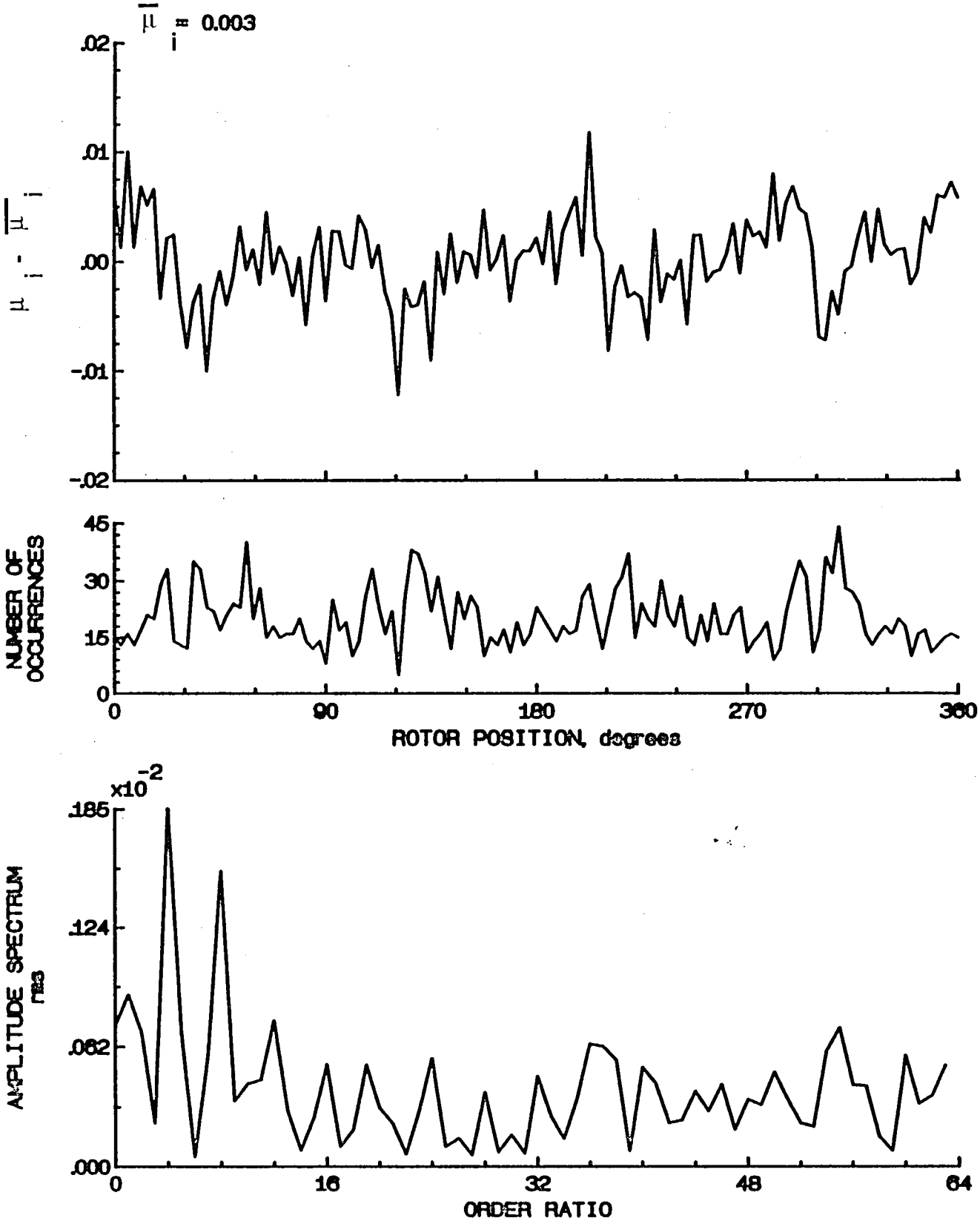
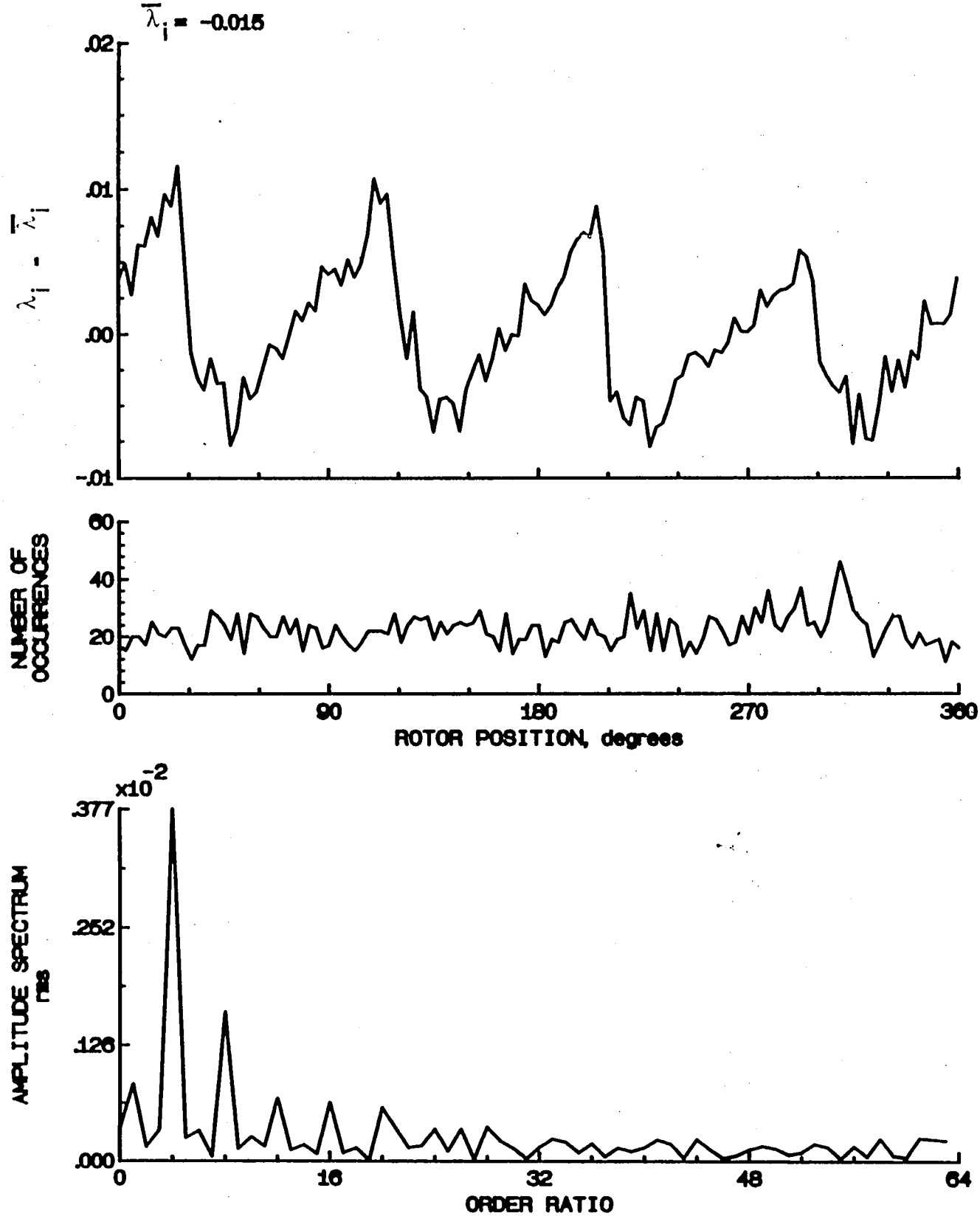


Figure 174.- Induced inflow velocity measured at 300 degrees and r/R of 0.98.



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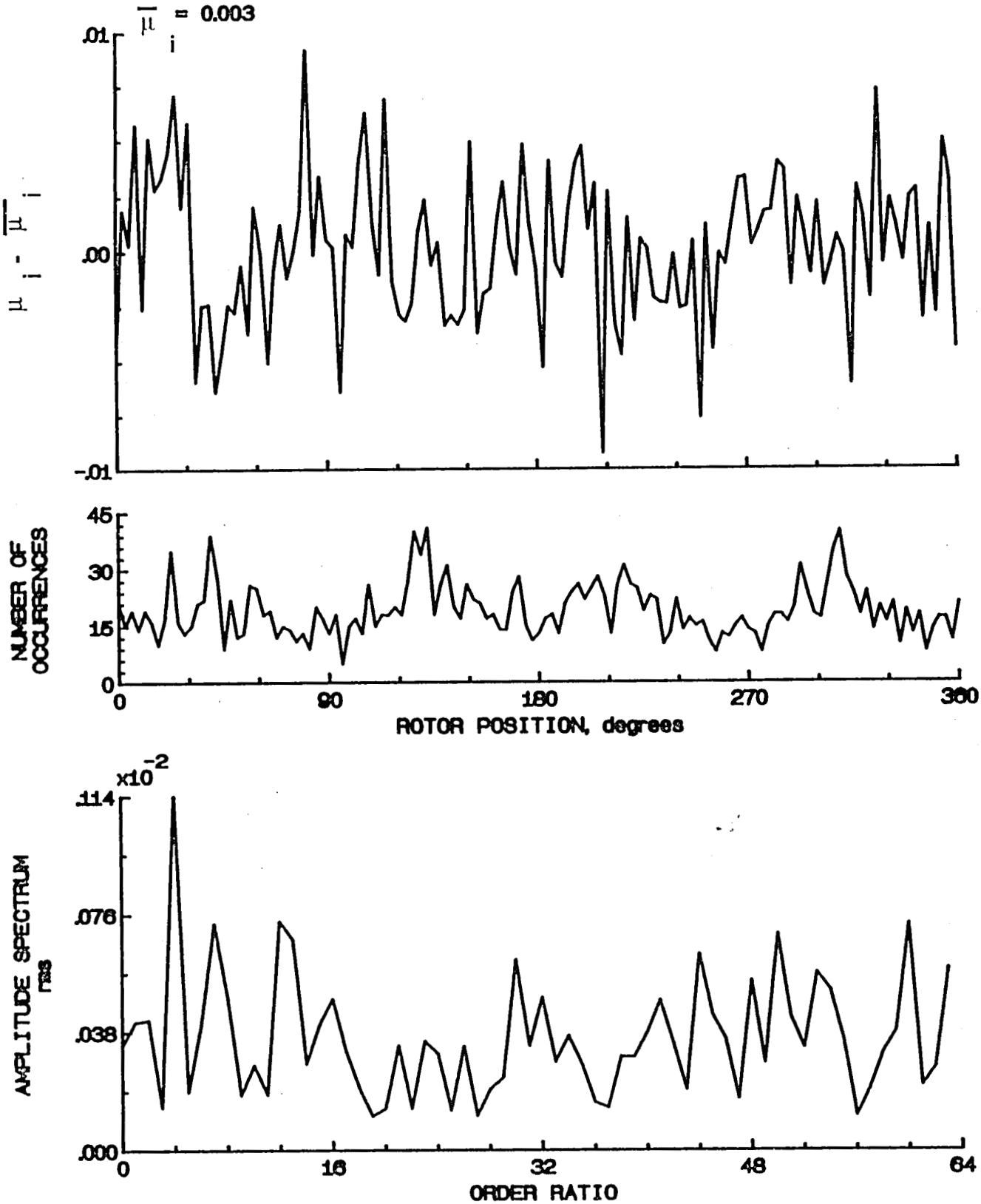
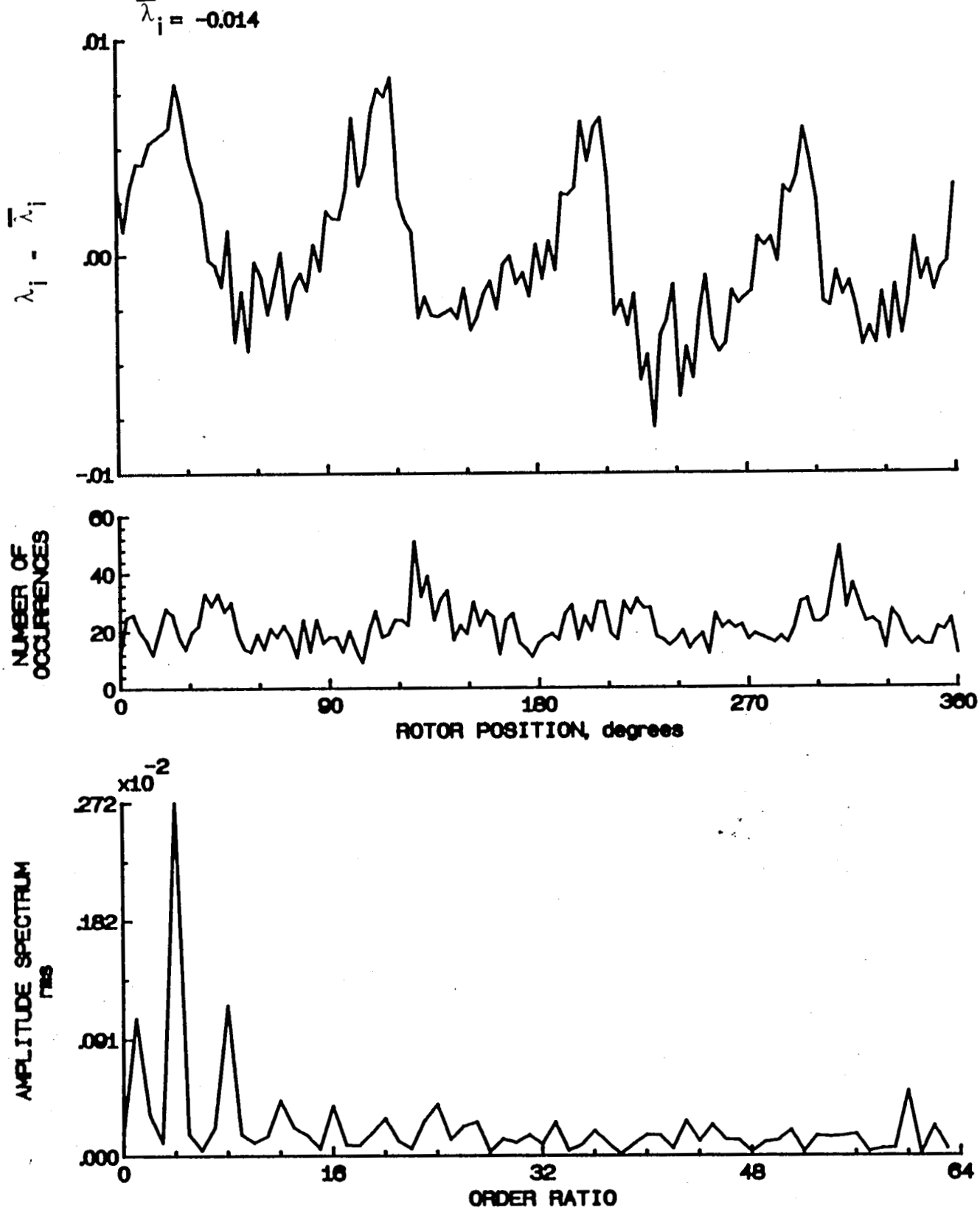


Figure 175.- Induced inflow velocity measured at 300 degrees and r/R of 1.02.



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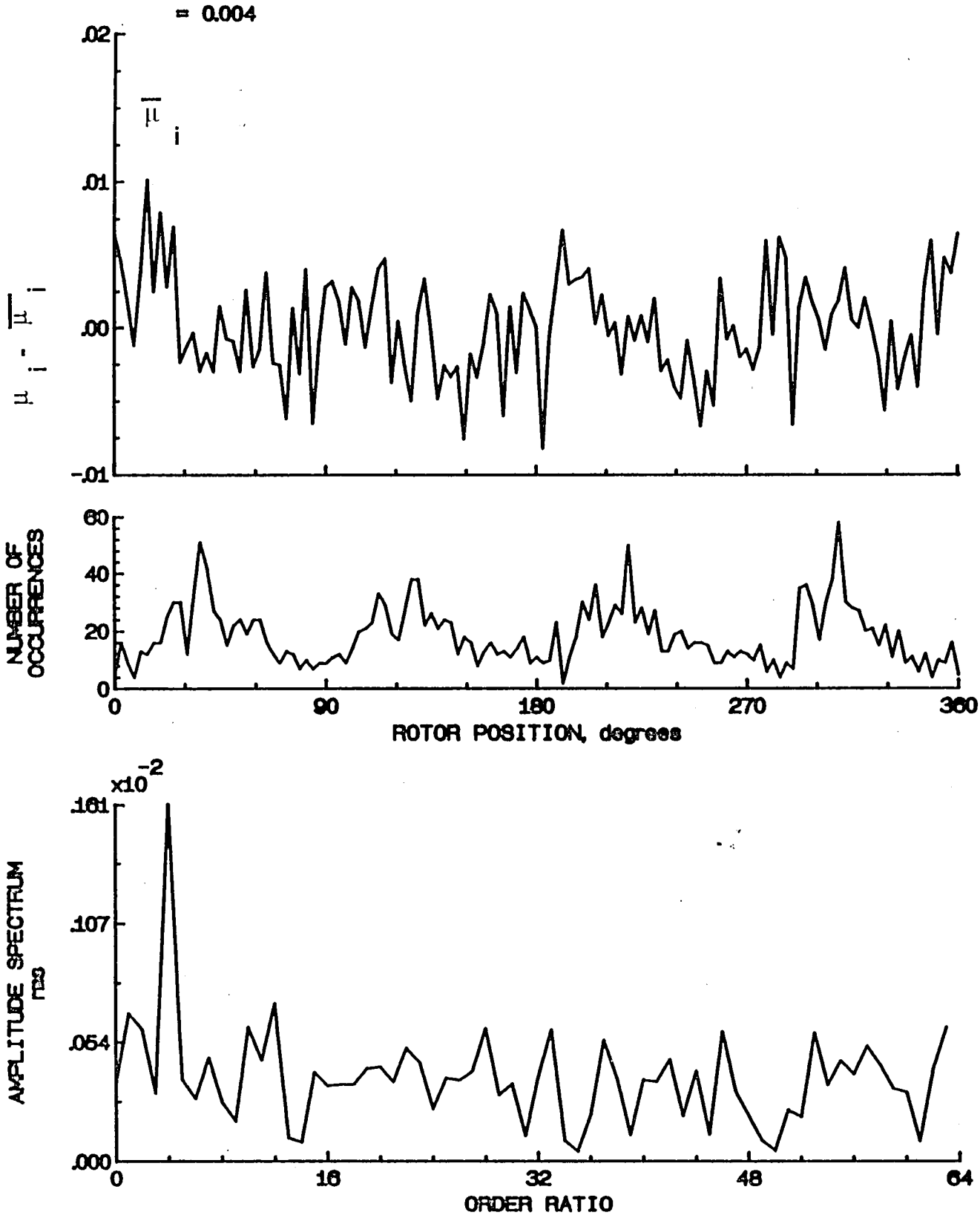
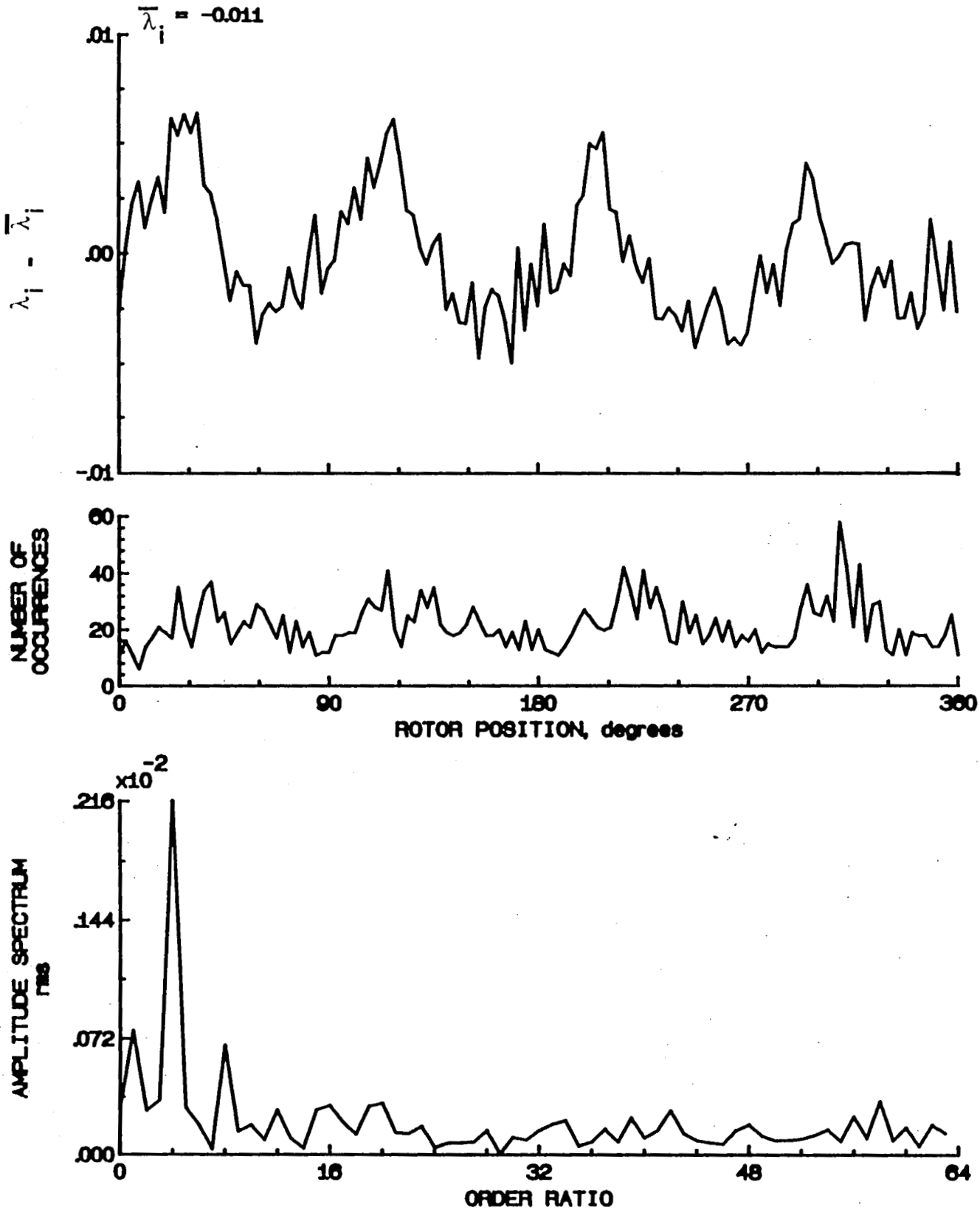


Figure 176.- Induced inflow velocity measured at 300 degrees and r/R of 1.04.



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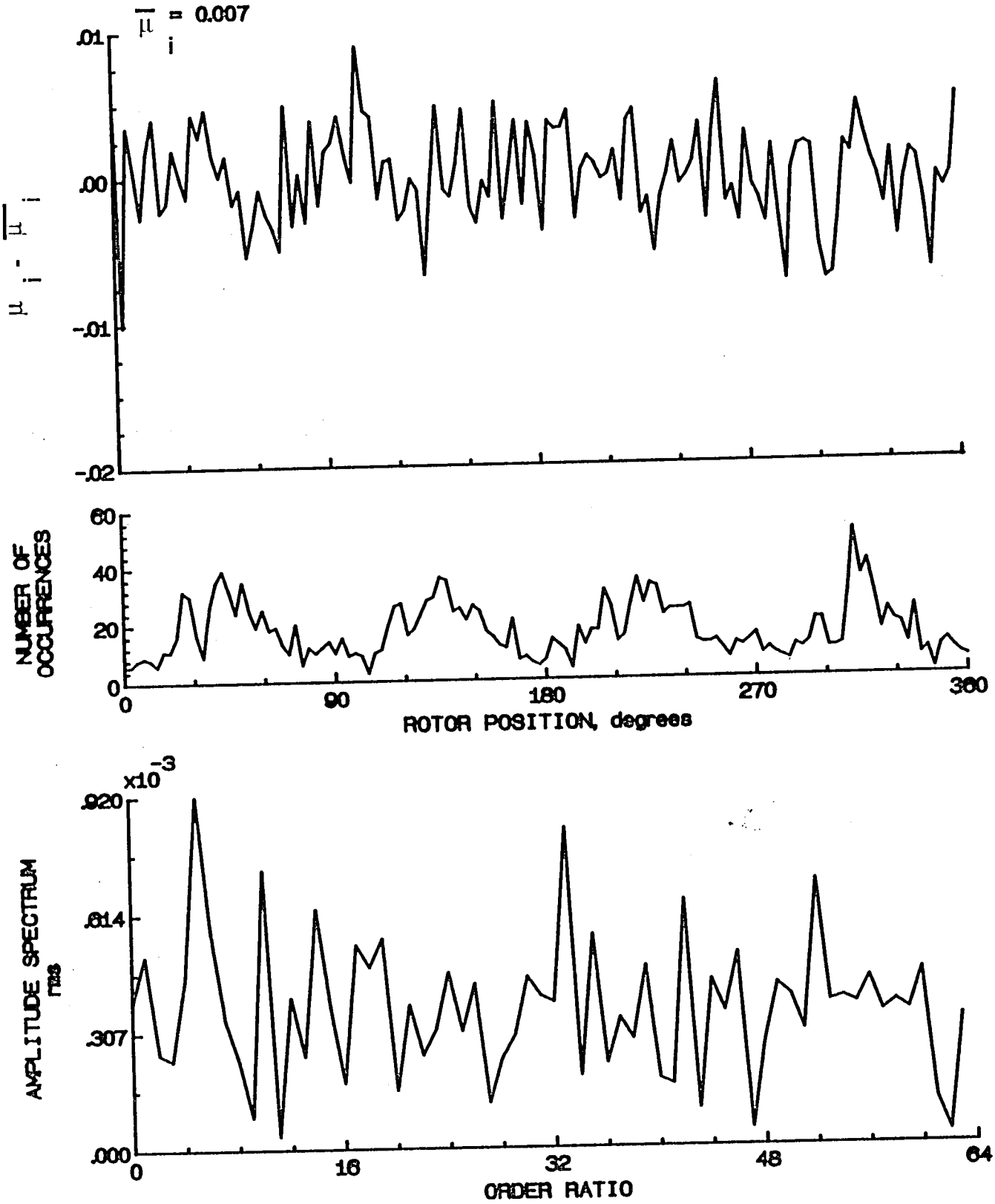
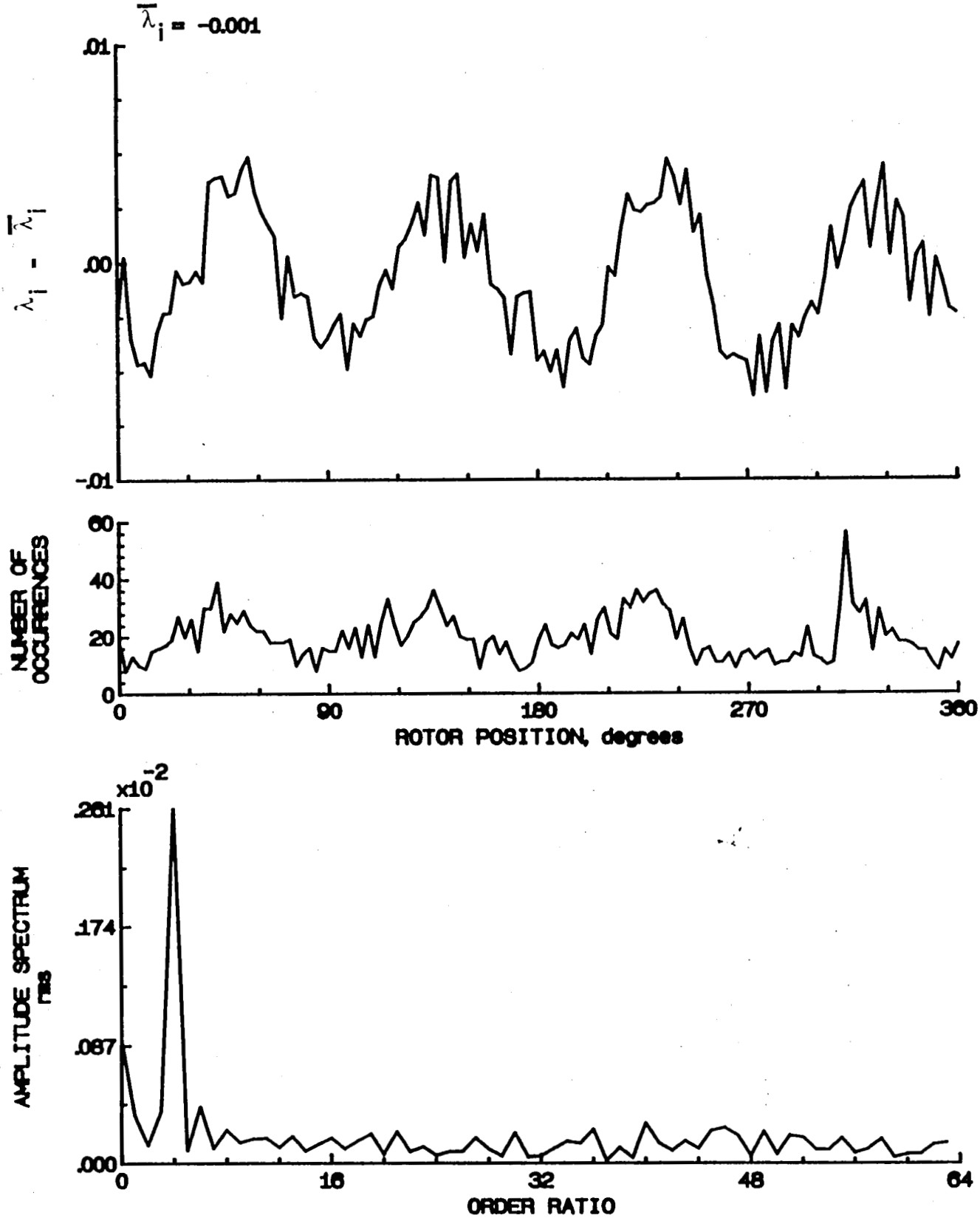


Figure 177.- Induced inflow velocity measured at 300 degrees and r/R of 1.10.



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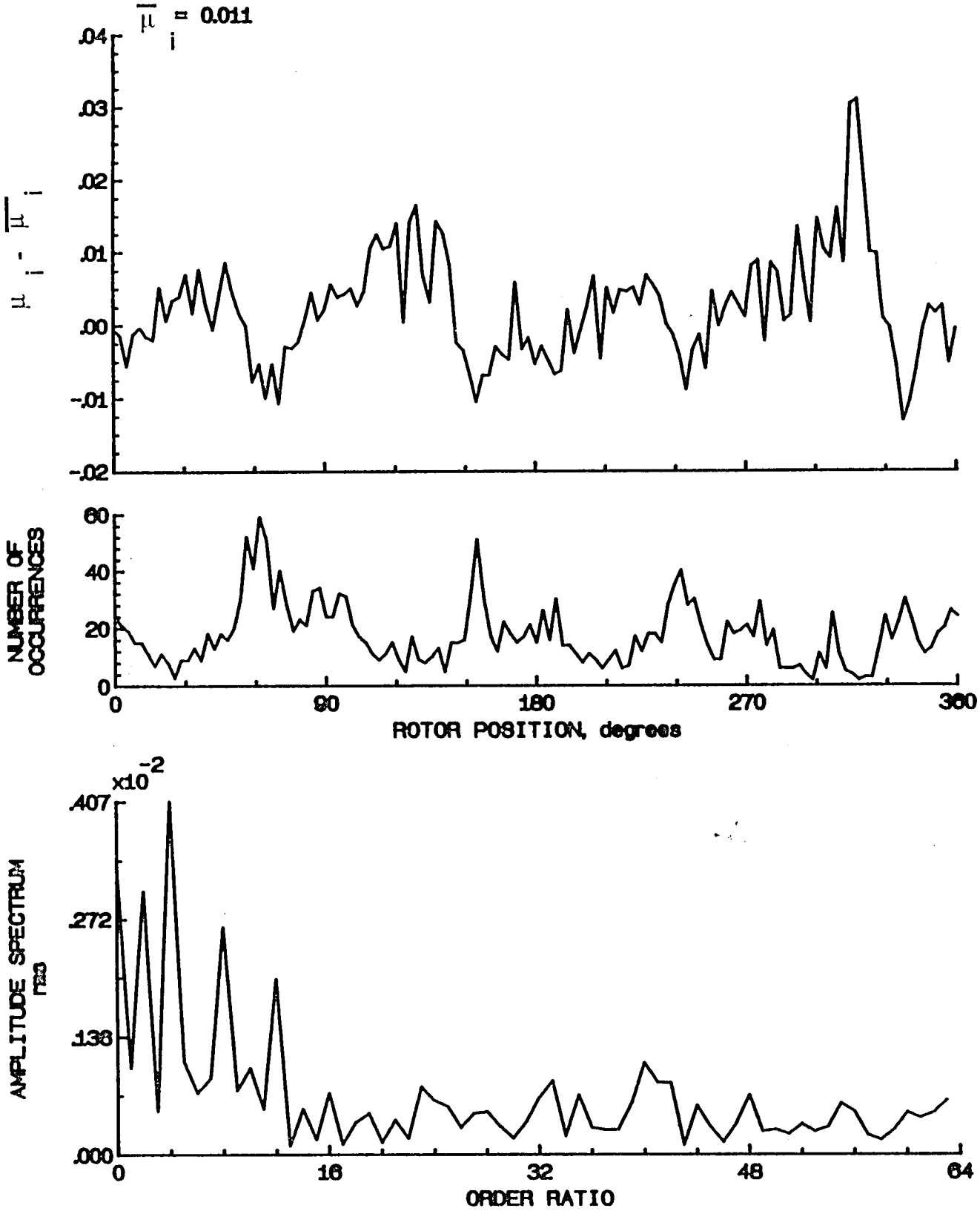
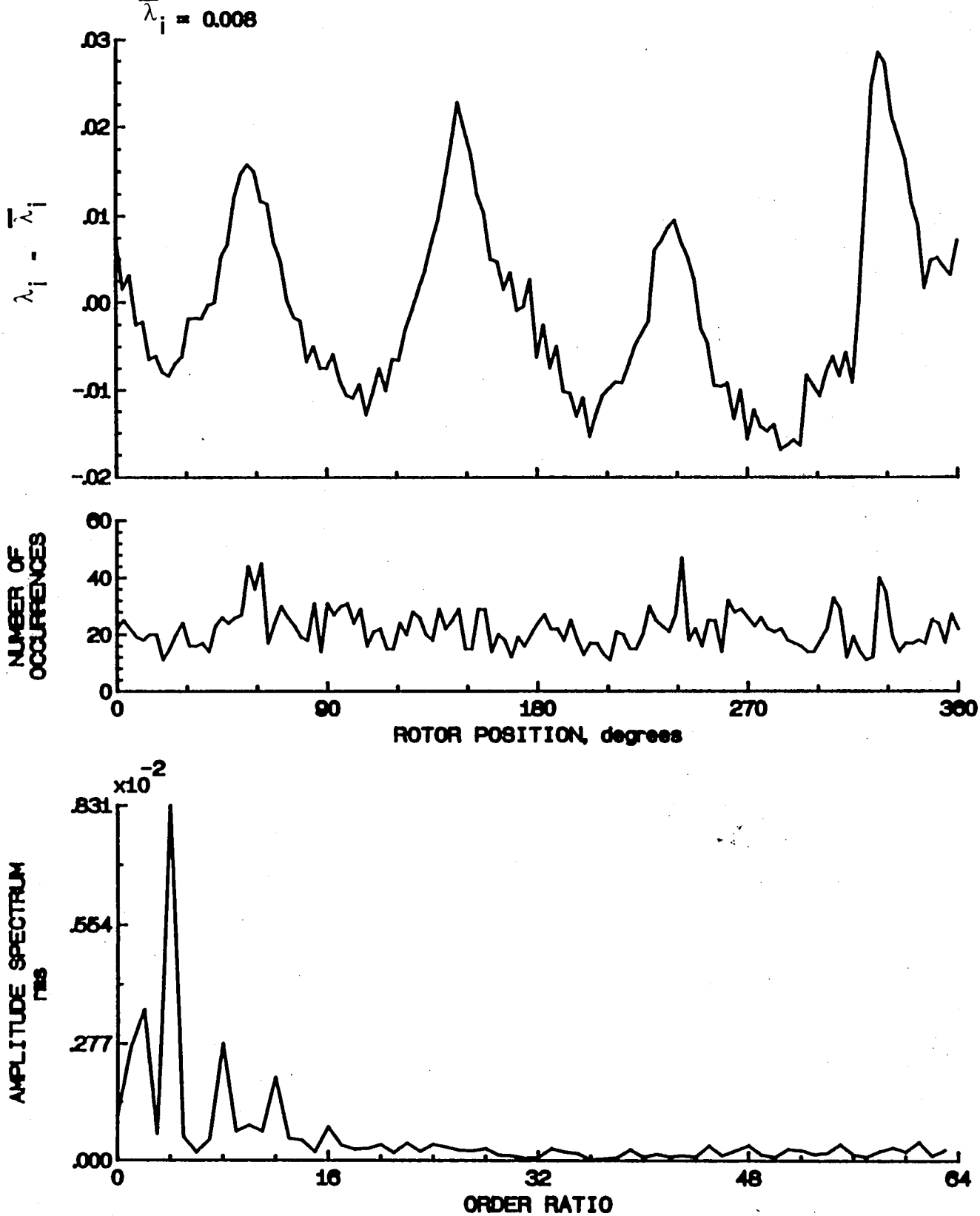


Figure 178.- Induced inflow velocity measured at 330 degrees and r/R of 0.20.



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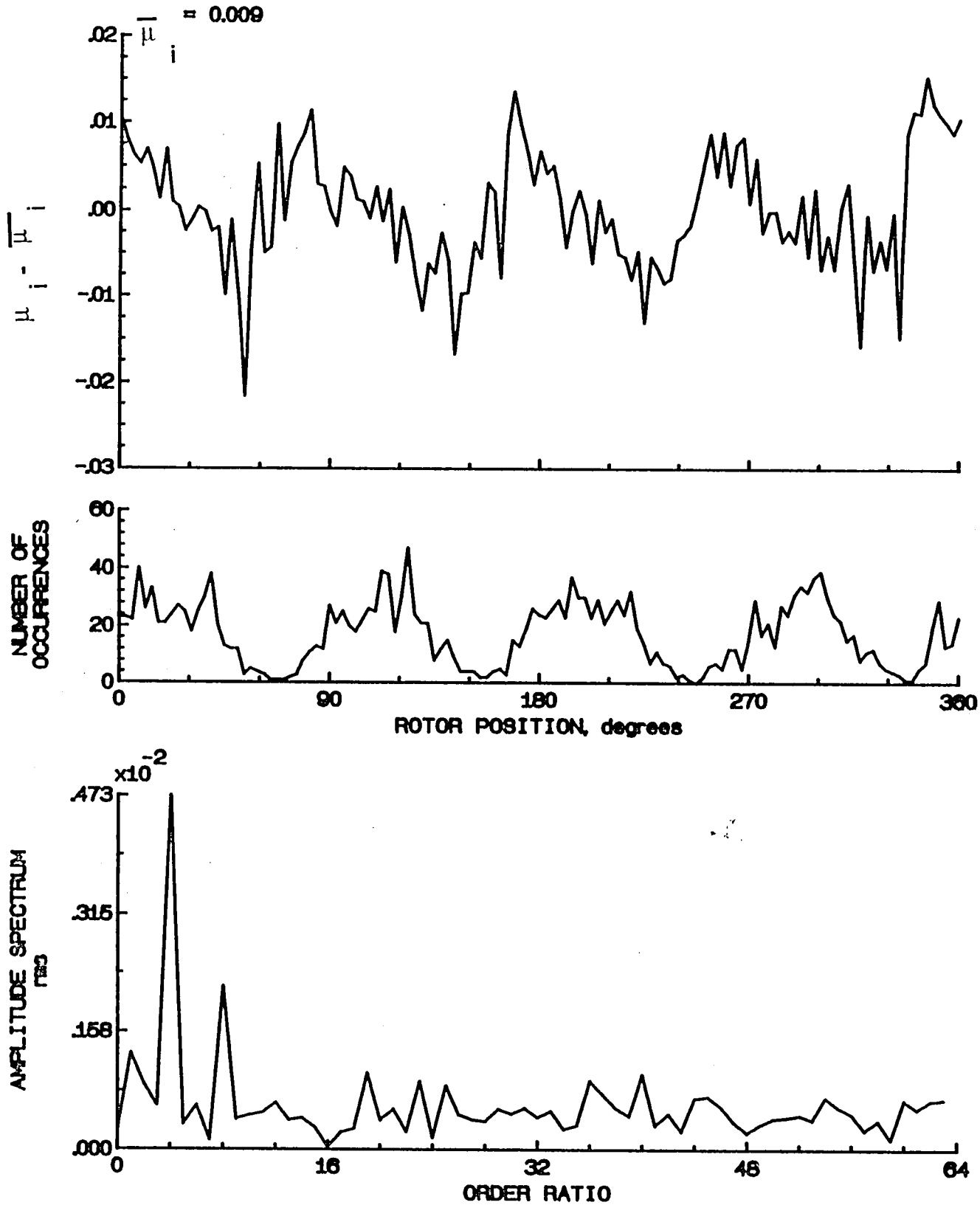
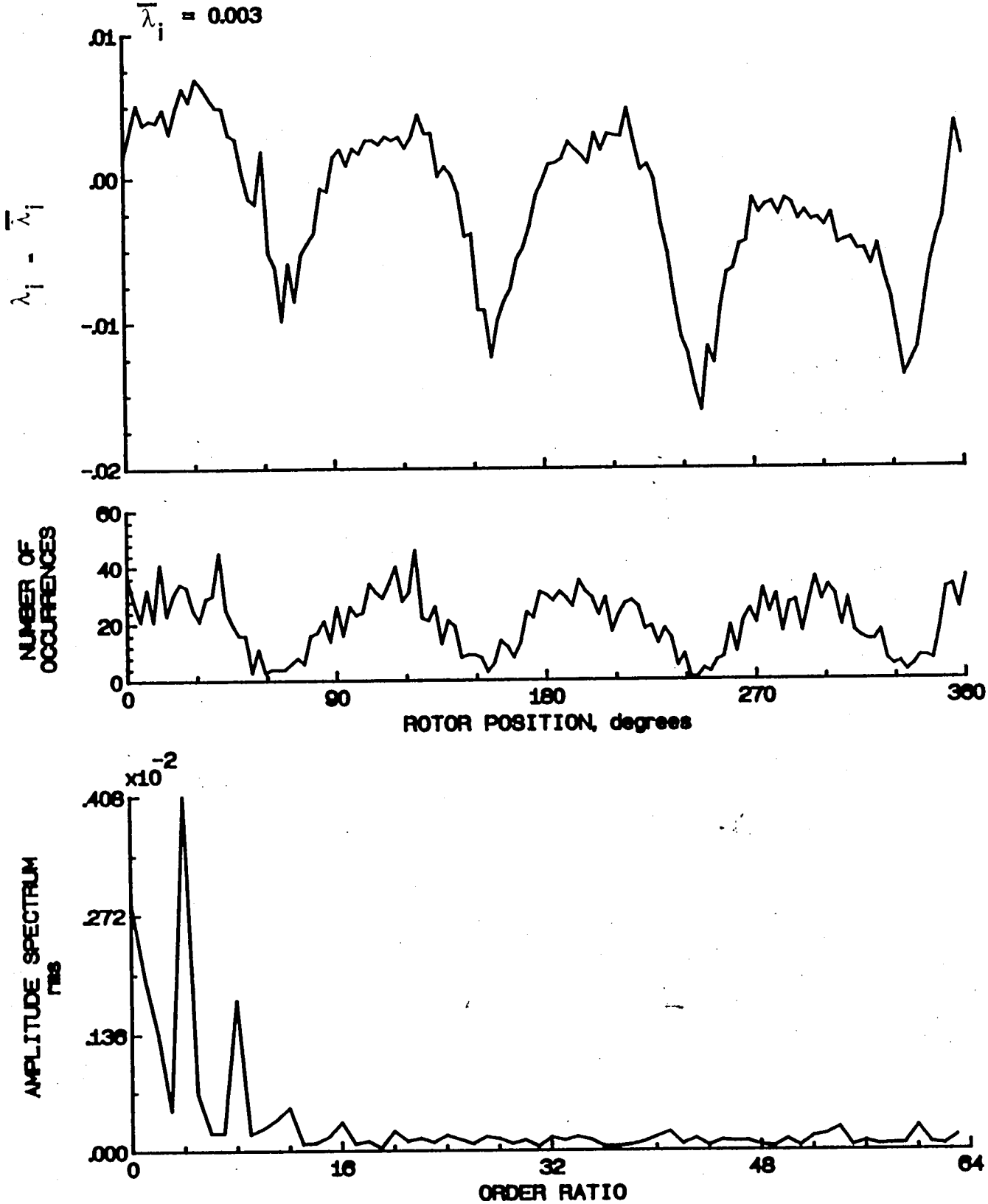


Figure 179.- Induced inflow velocity measured at 330 degrees and r/R of 0.40.



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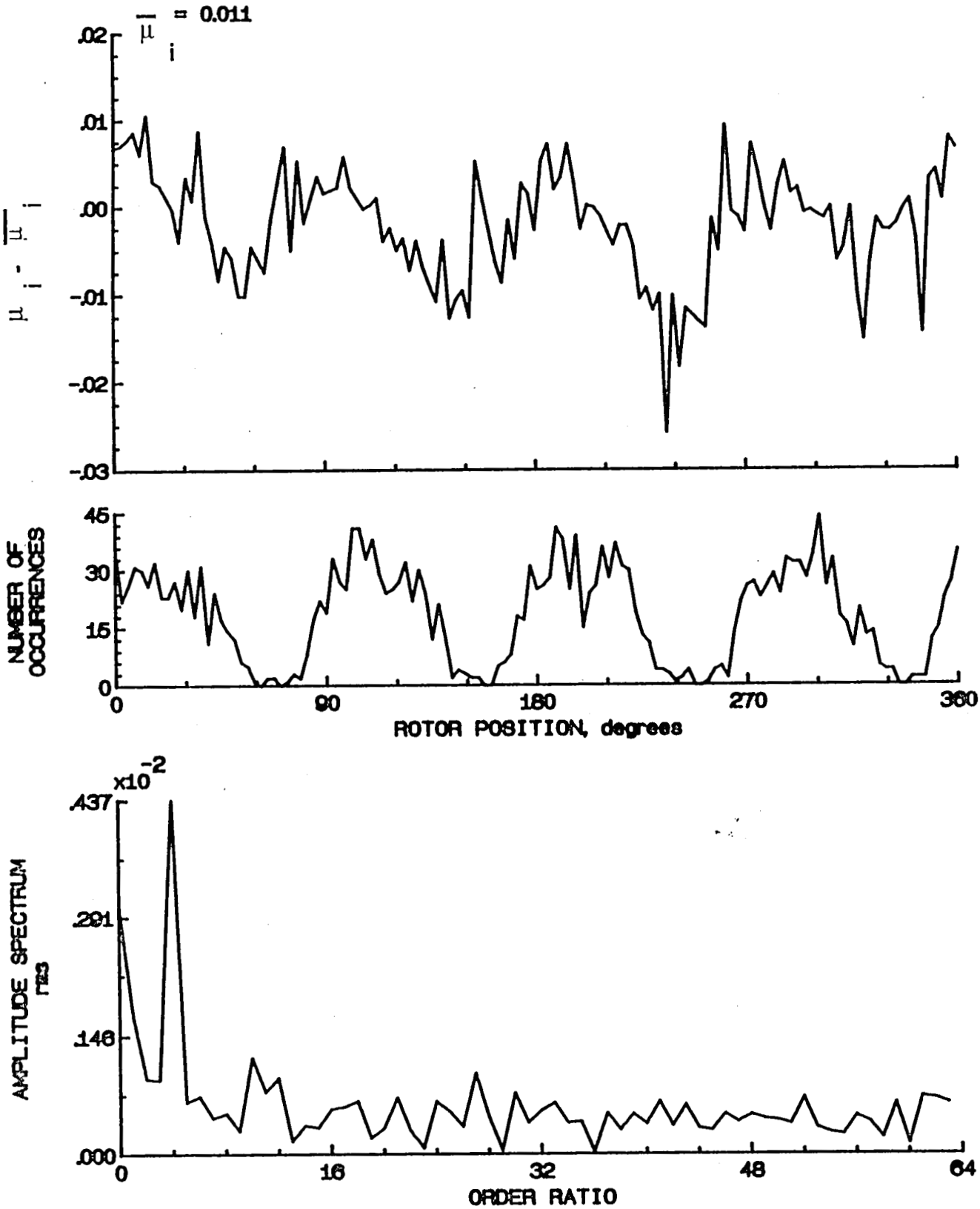
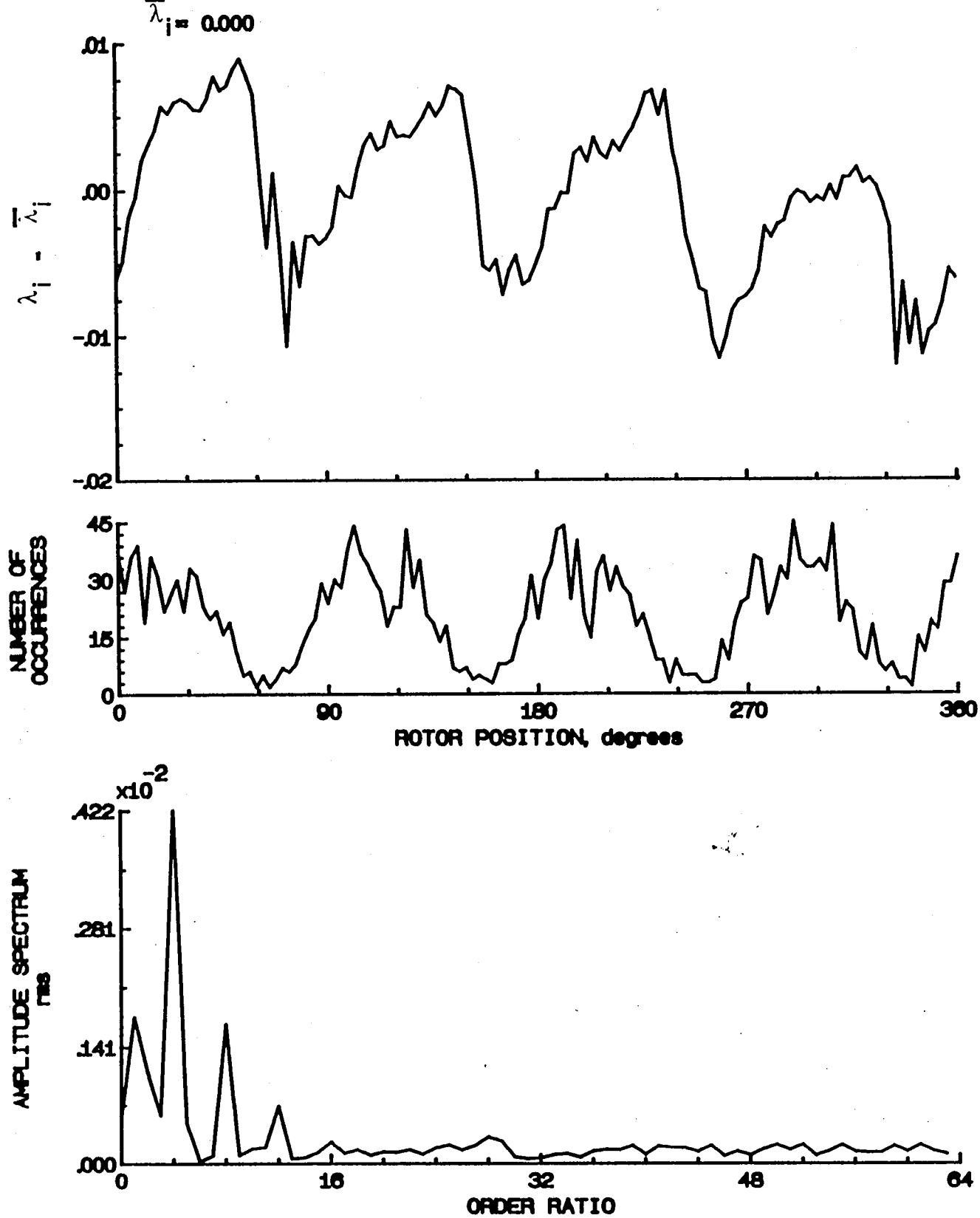


Figure 180.- Induced inflow velocity measured at 330 degrees and r/R of 0.50.



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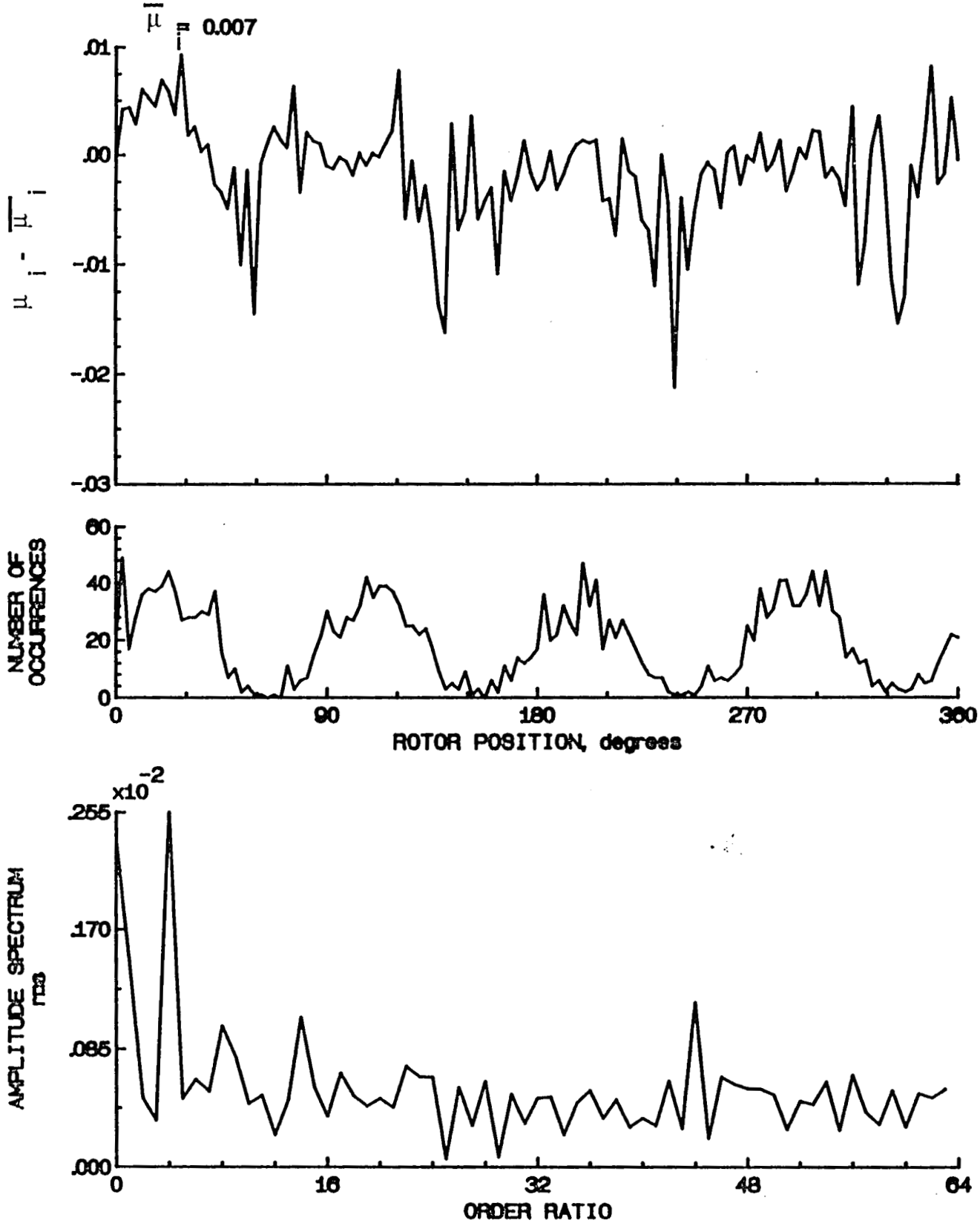
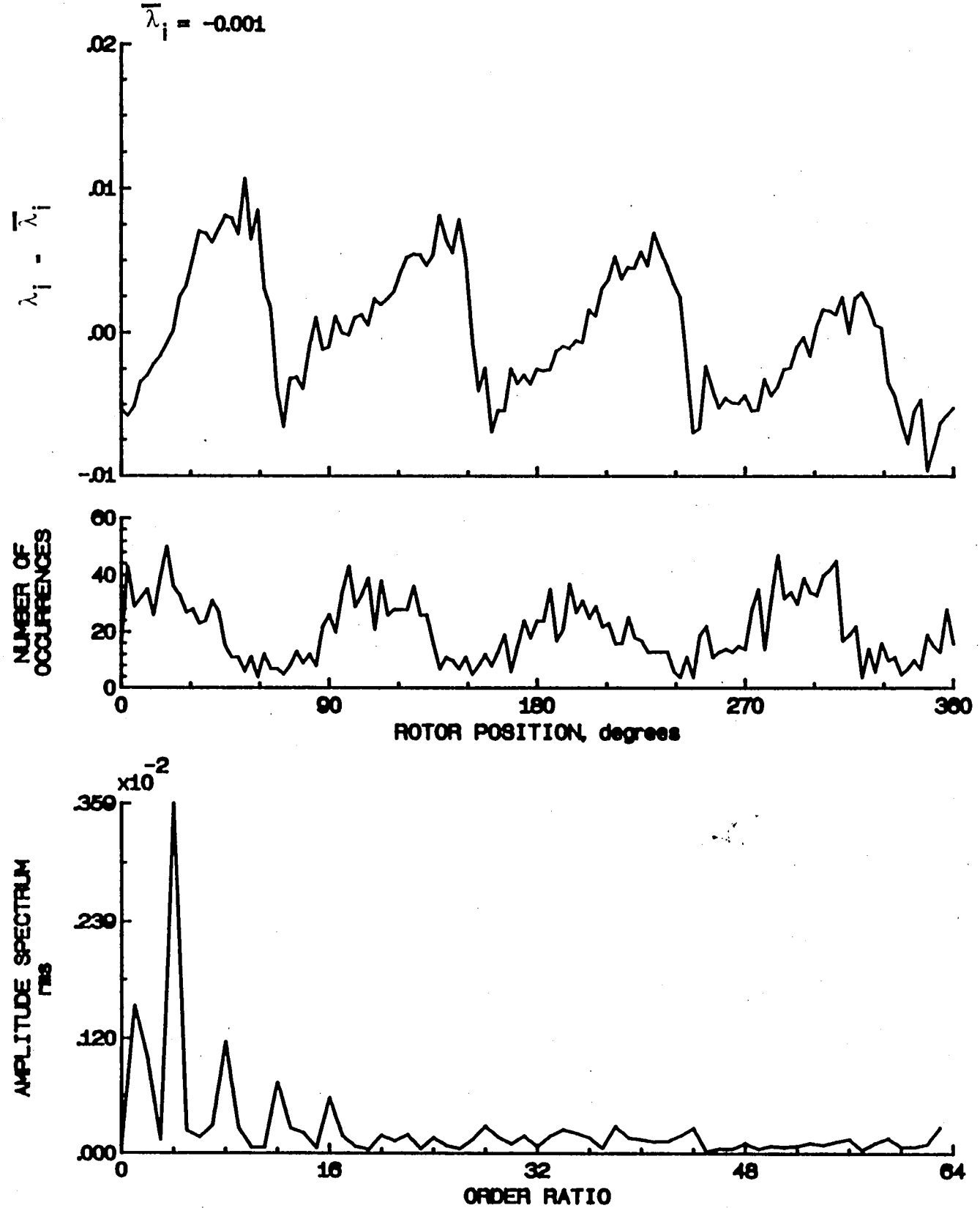


Figure 181.- Induced inflow velocity measured at 330 degrees and r/R of 0.60.



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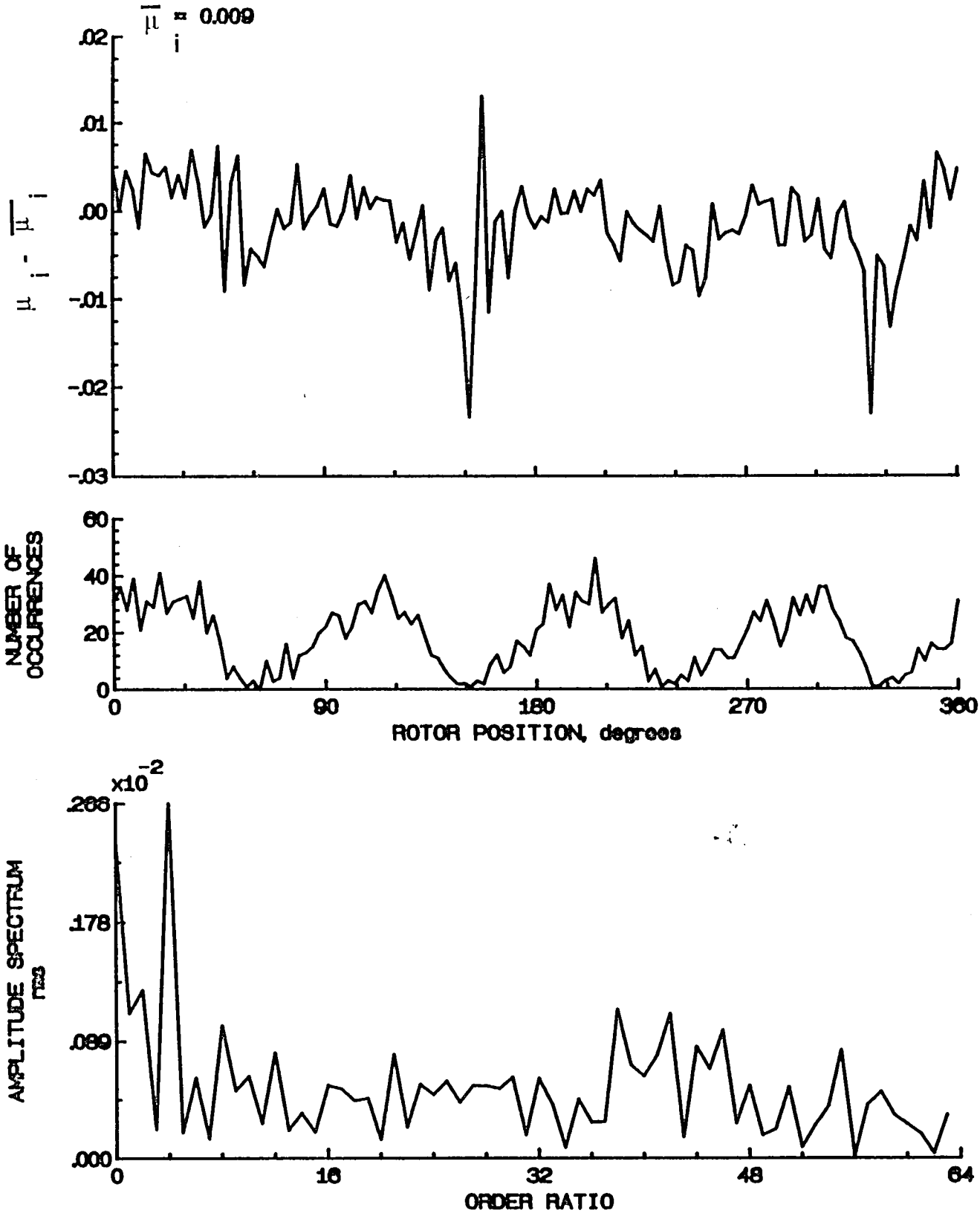
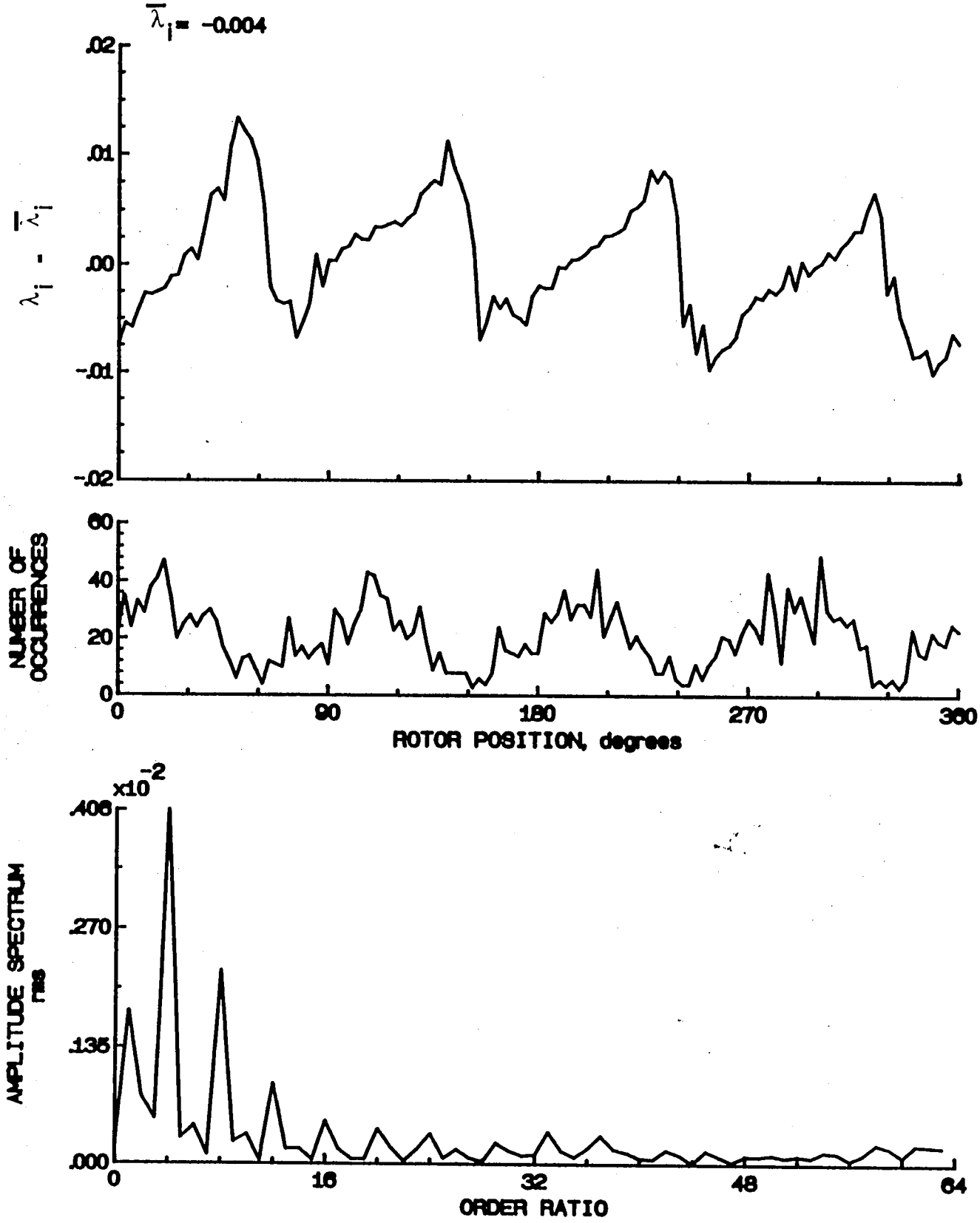


Figure 182.- Induced inflow velocity measured at 330 degrees and r/R of 0.70.



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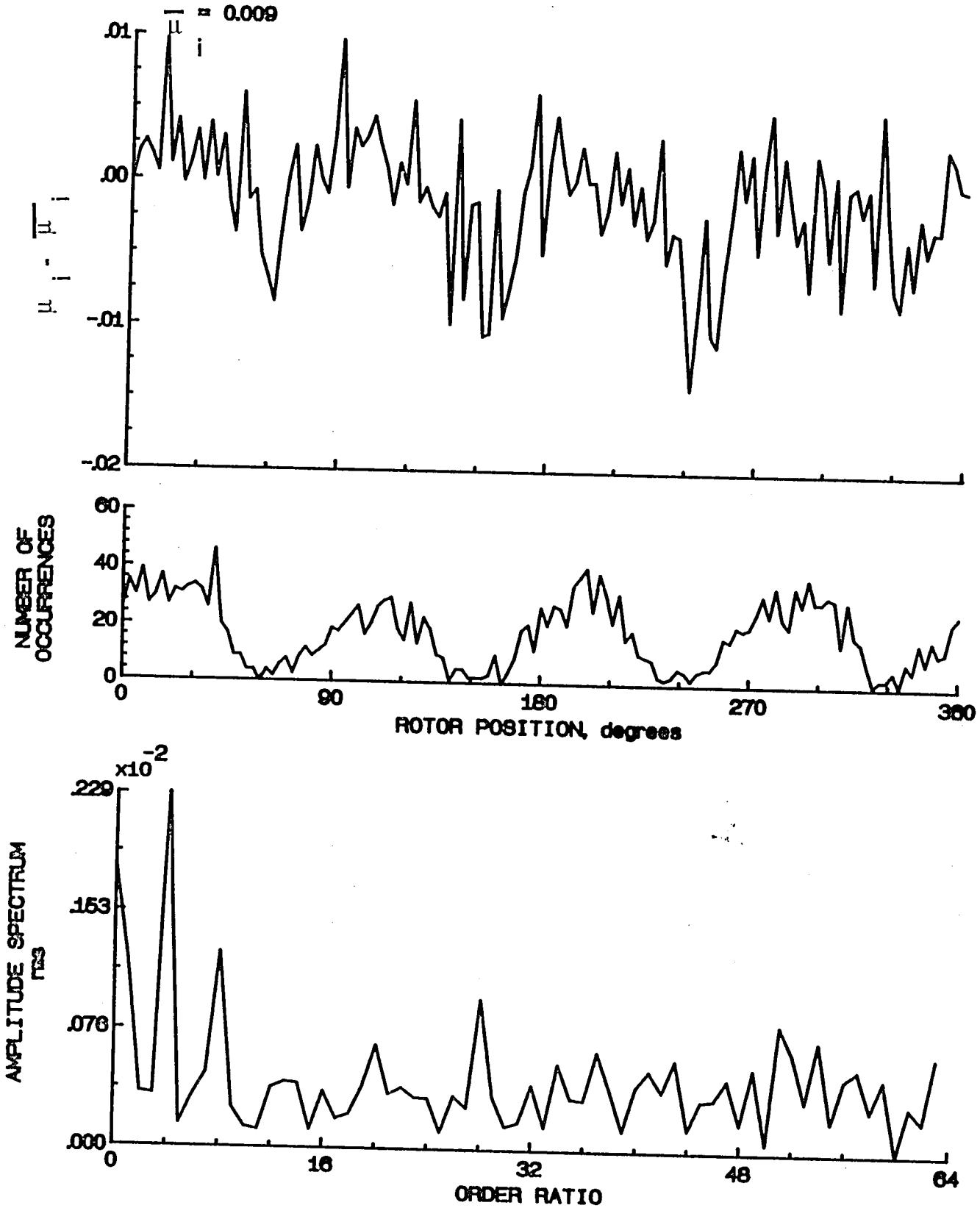
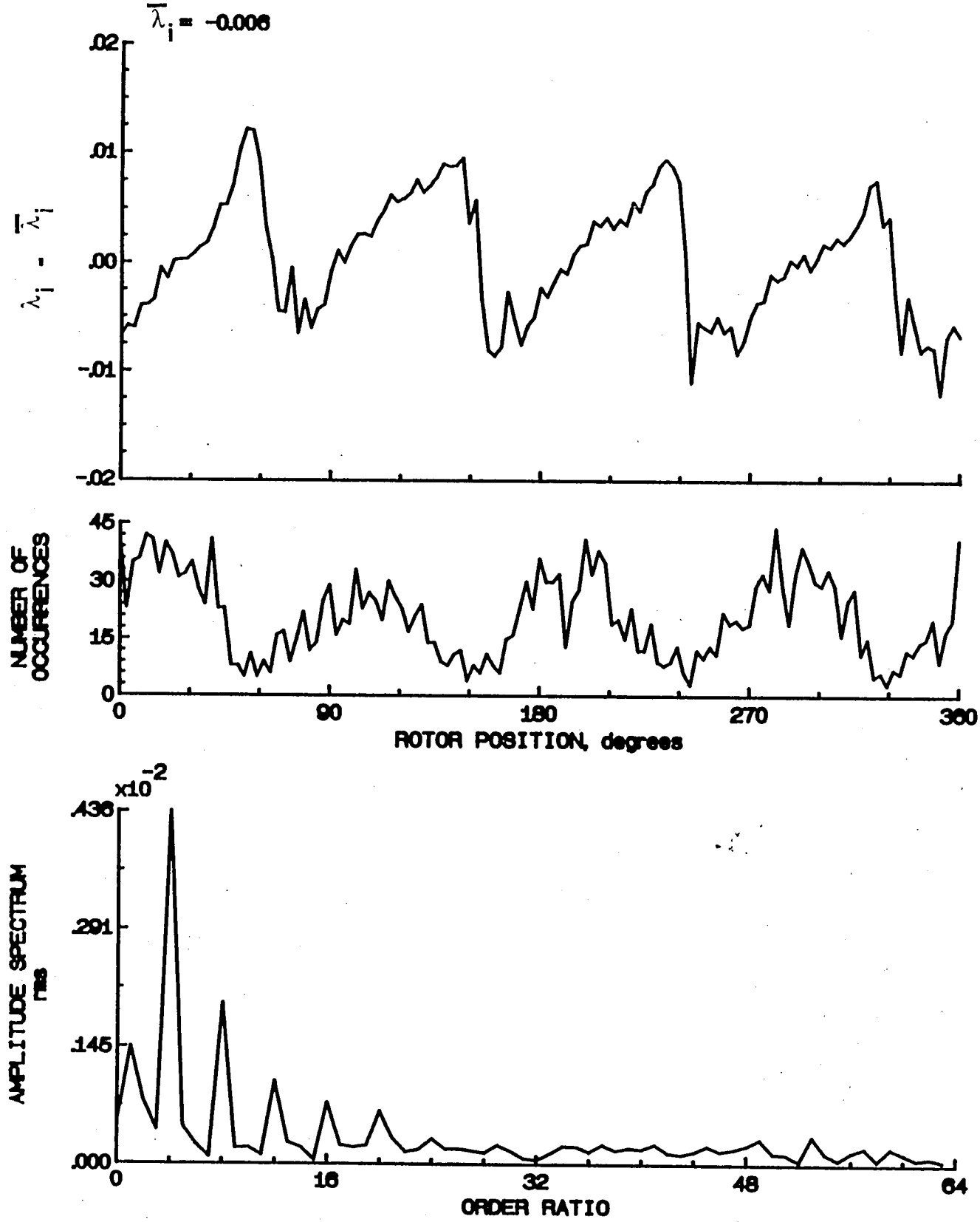


Figure 183.- Induced inflow velocity measured at 330 degrees and r/R of 0.74.



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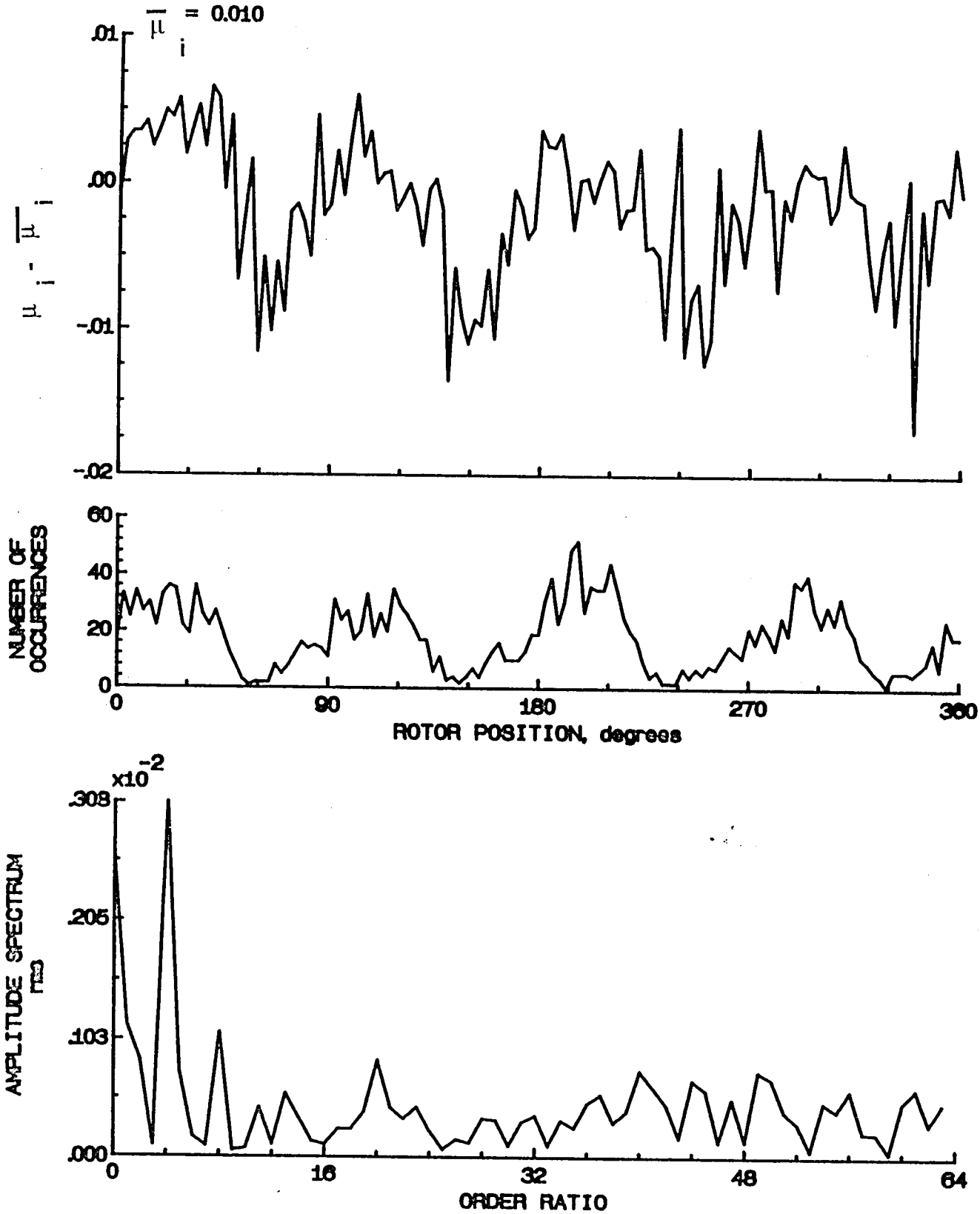
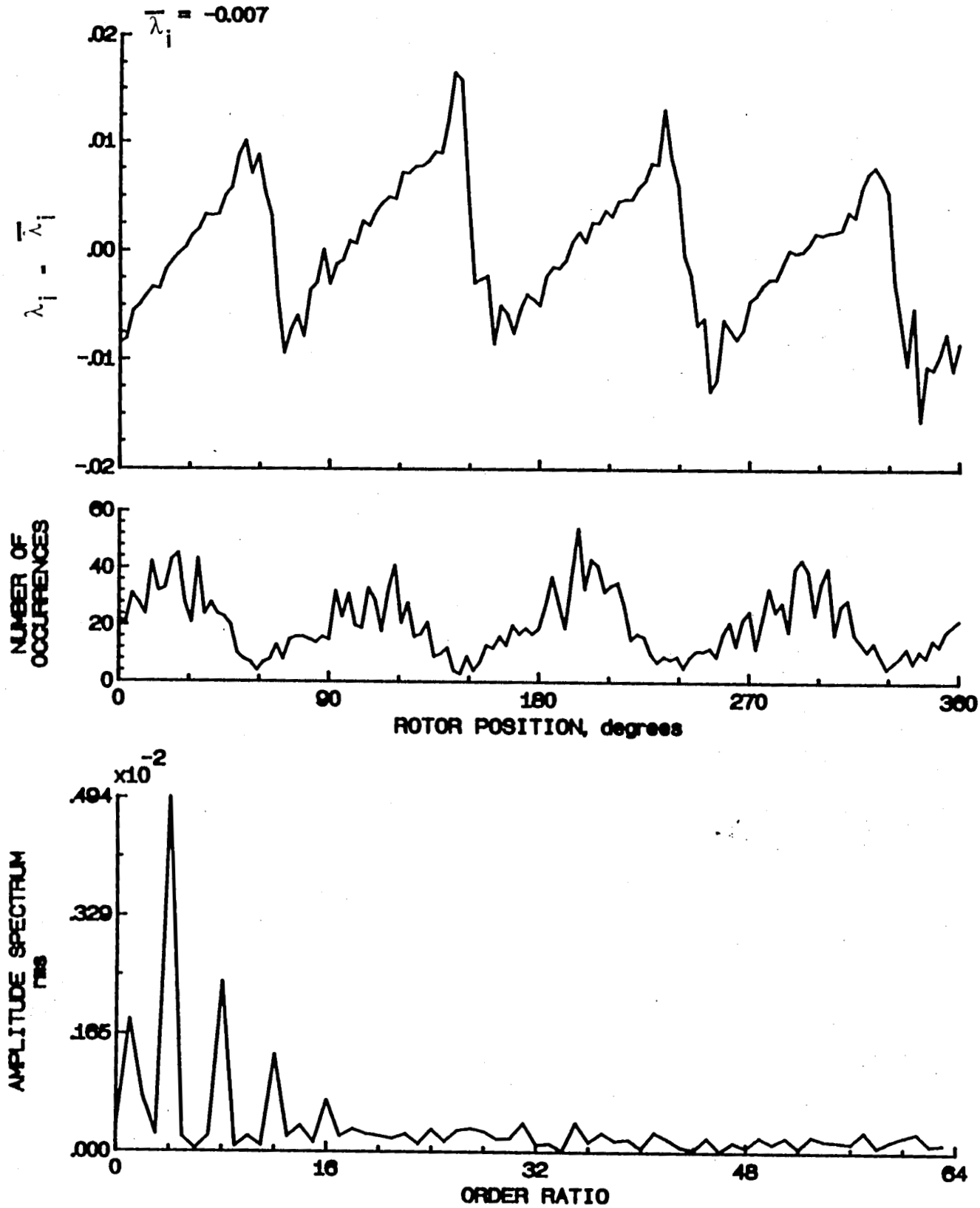


Figure 184.- Induced inflow velocity measured at 330 degrees and r/R of 0.78.



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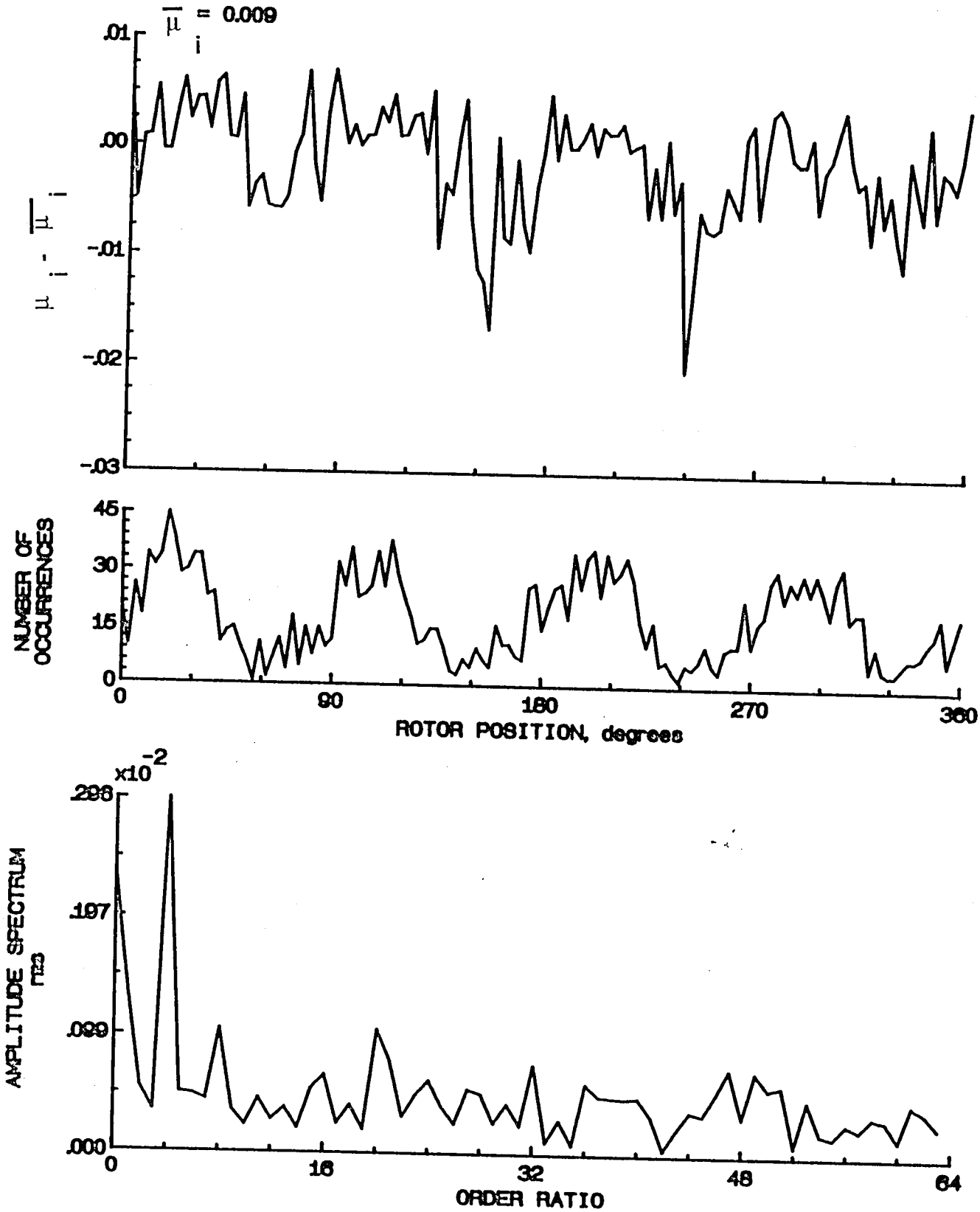
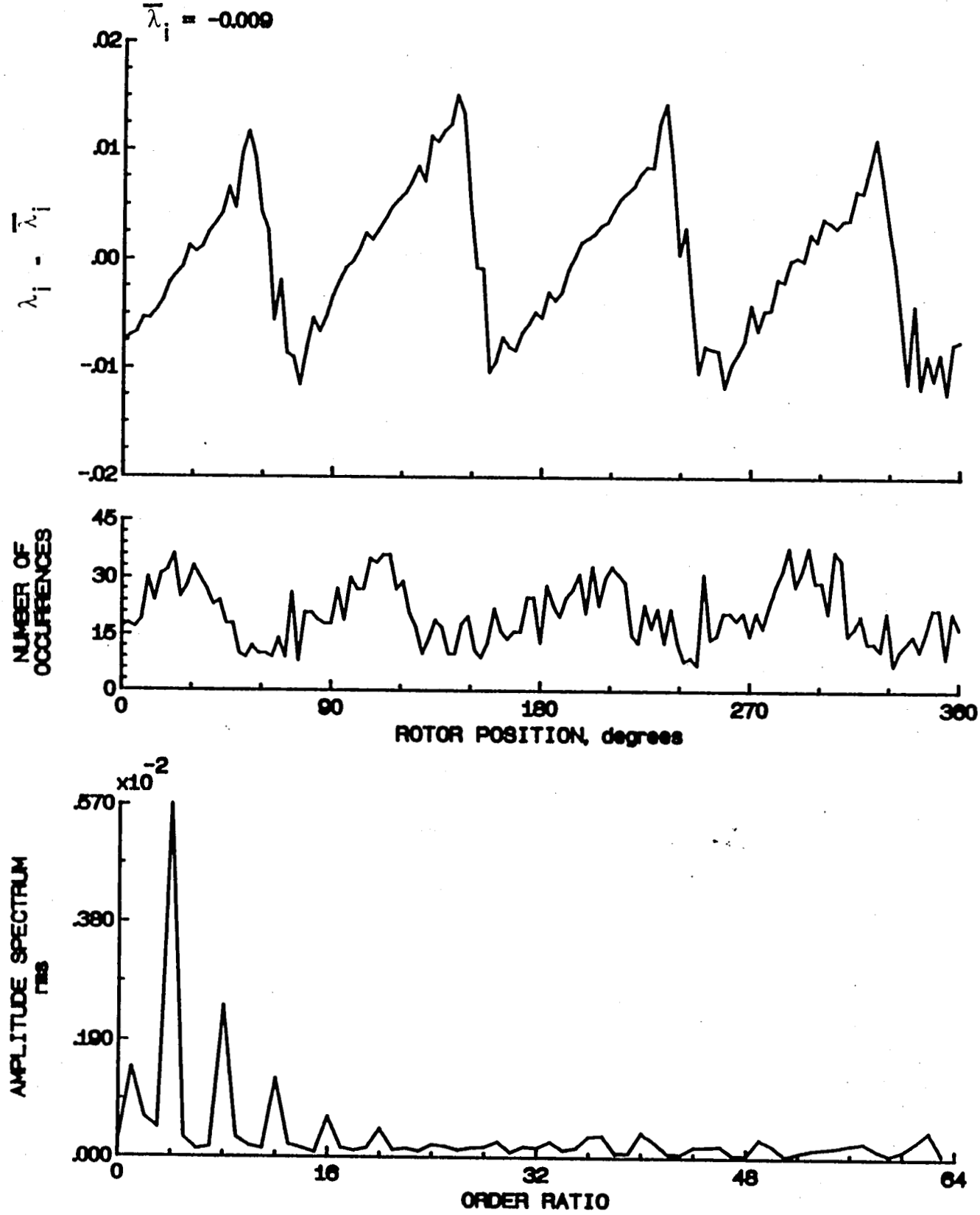


Figure 185.- Induced inflow velocity measured at 330 degrees and r/R of 0.82.



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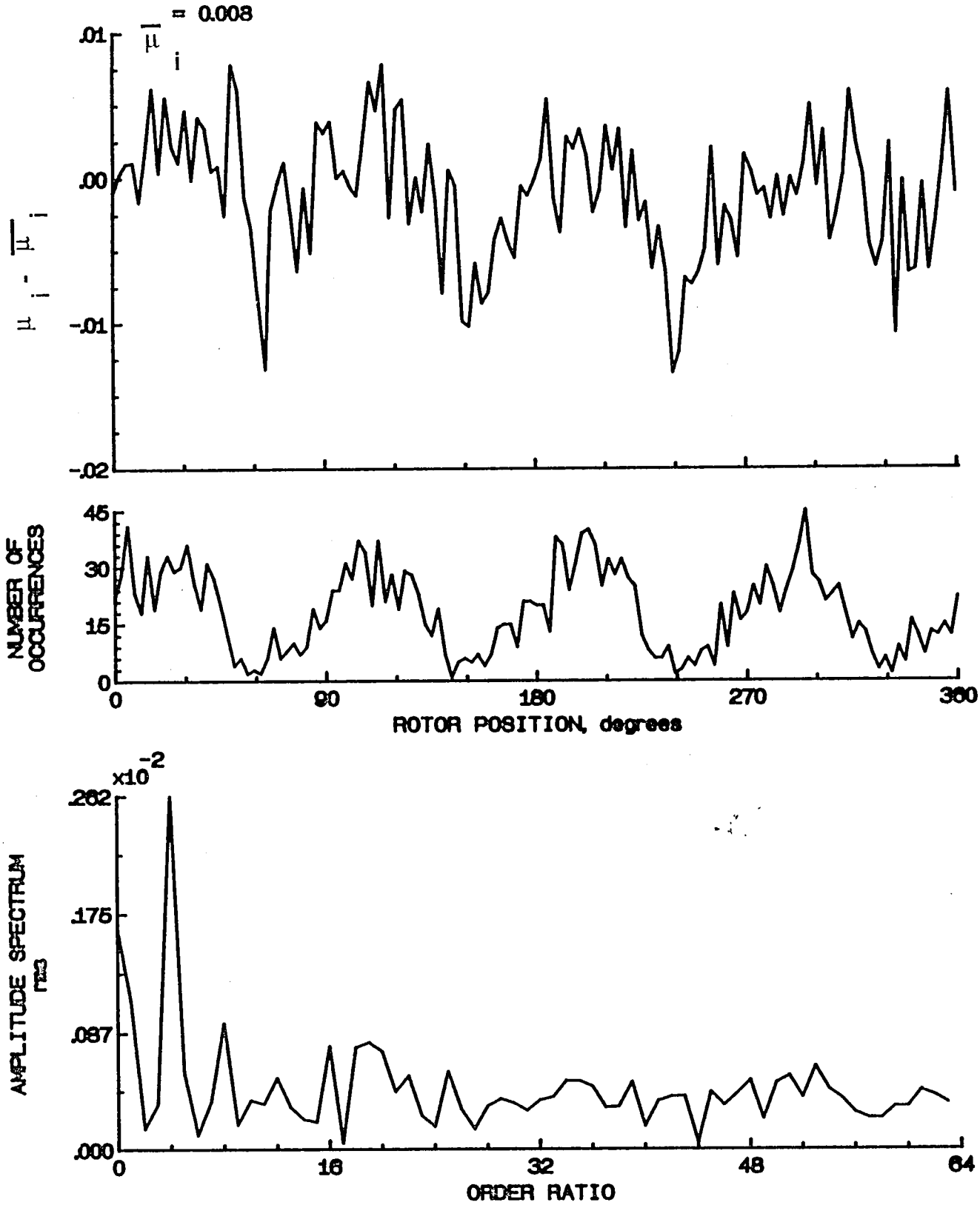
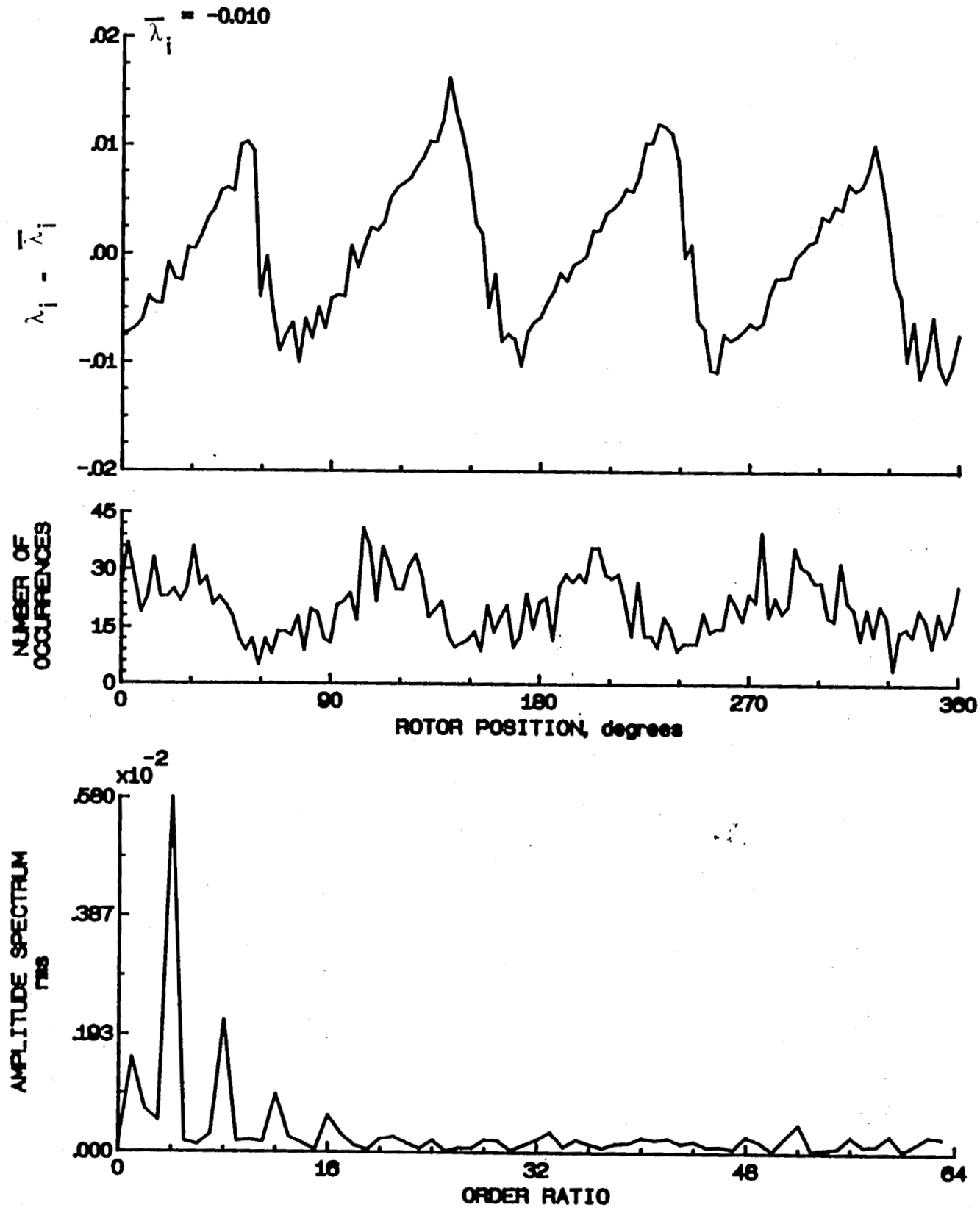


Figure 186.- Induced inflow velocity measured at 330 degrees and r/R of 0.86.



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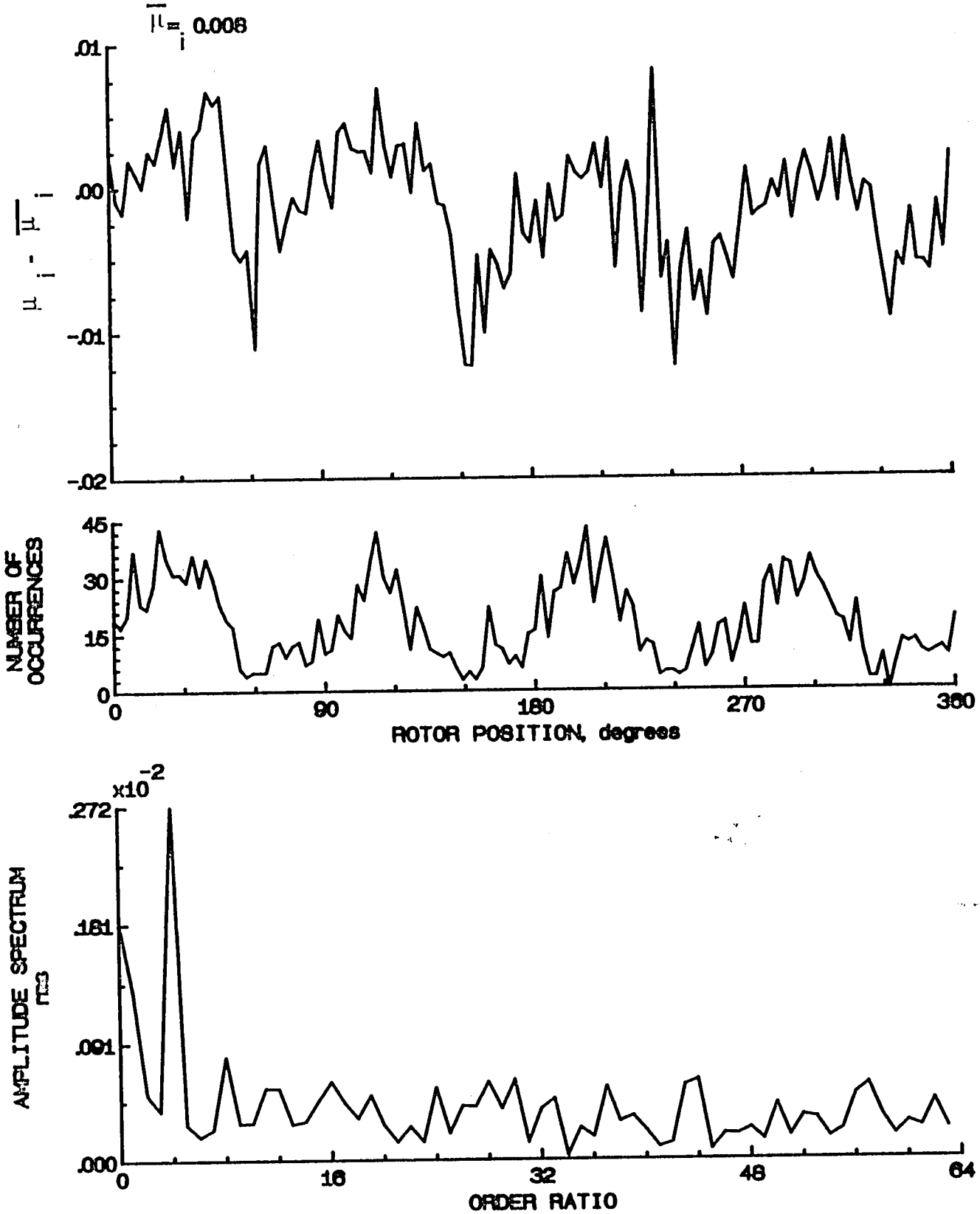
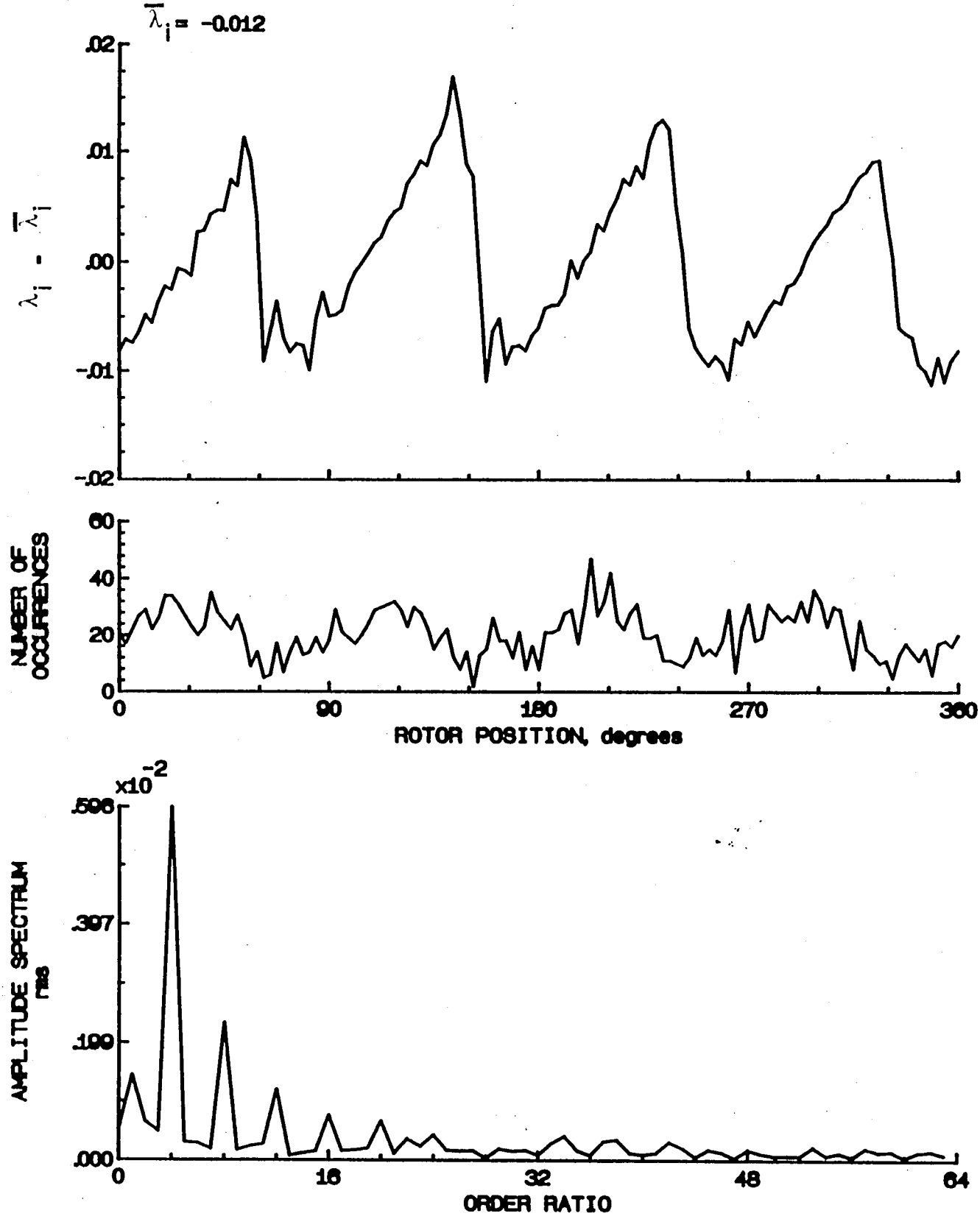


Figure 187.- Induced inflow velocity measured at 330 degrees and r/R of 0.90.



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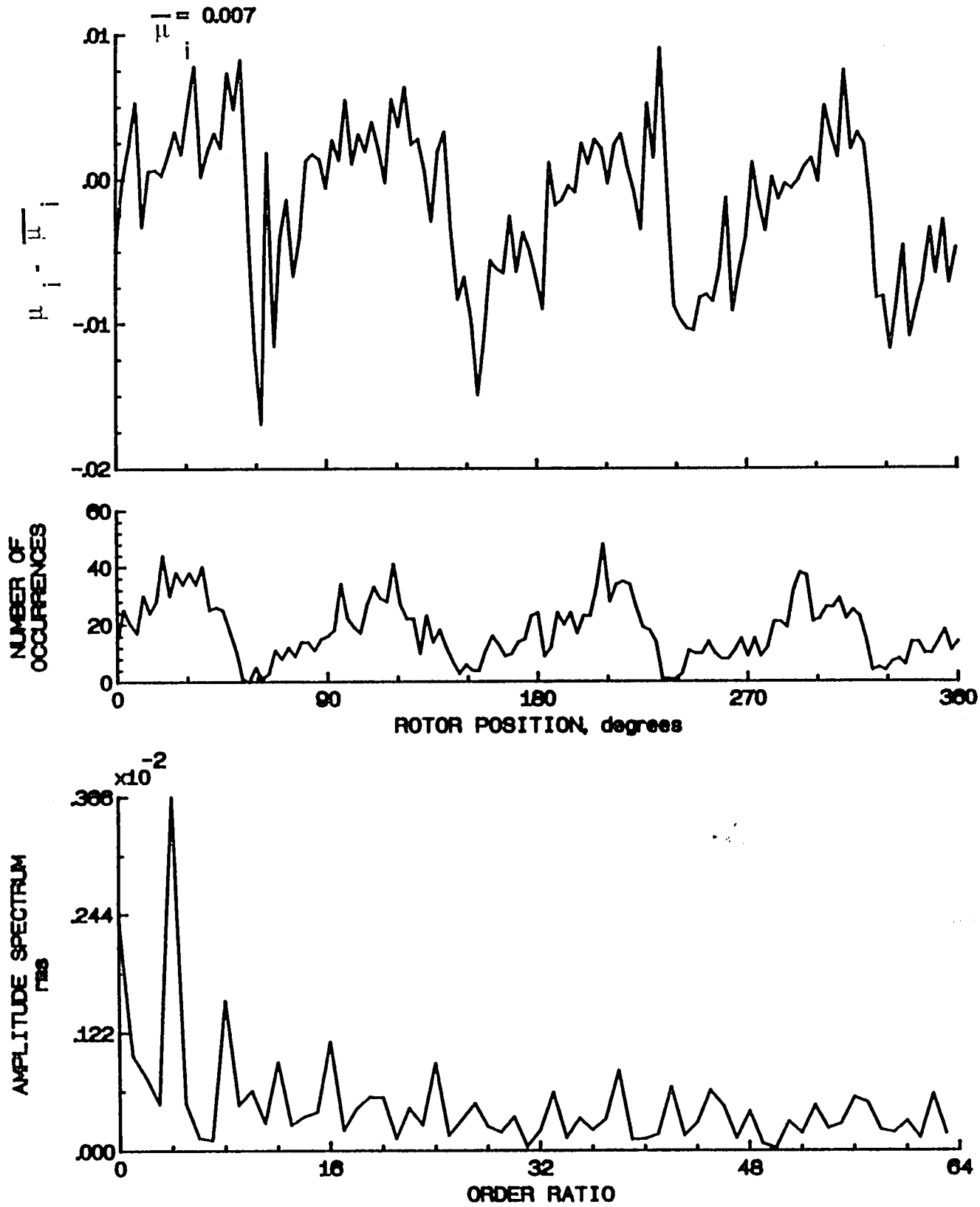
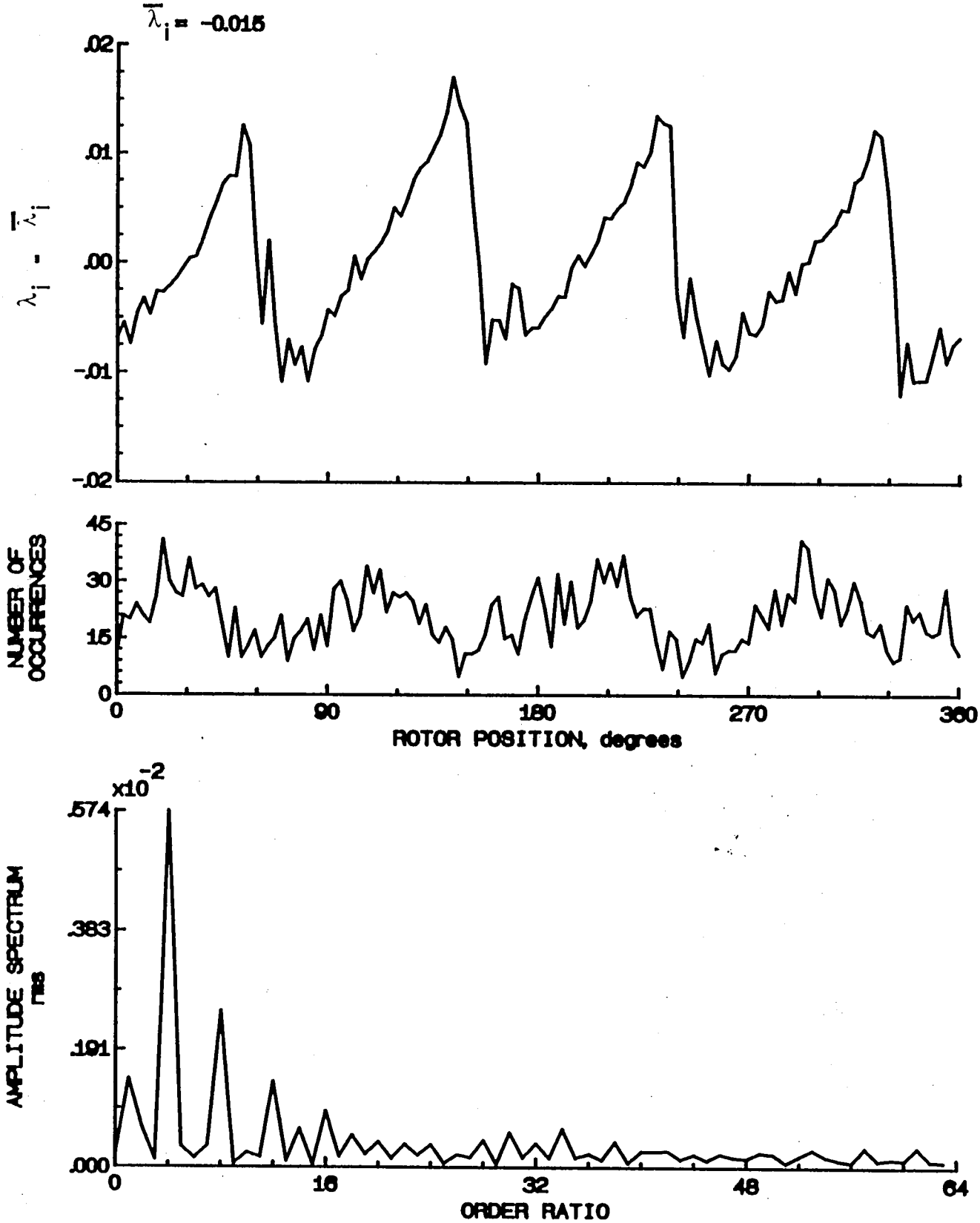


Figure 188.- Induced inflow velocity measured at 330 degrees and r/R of 0.94.



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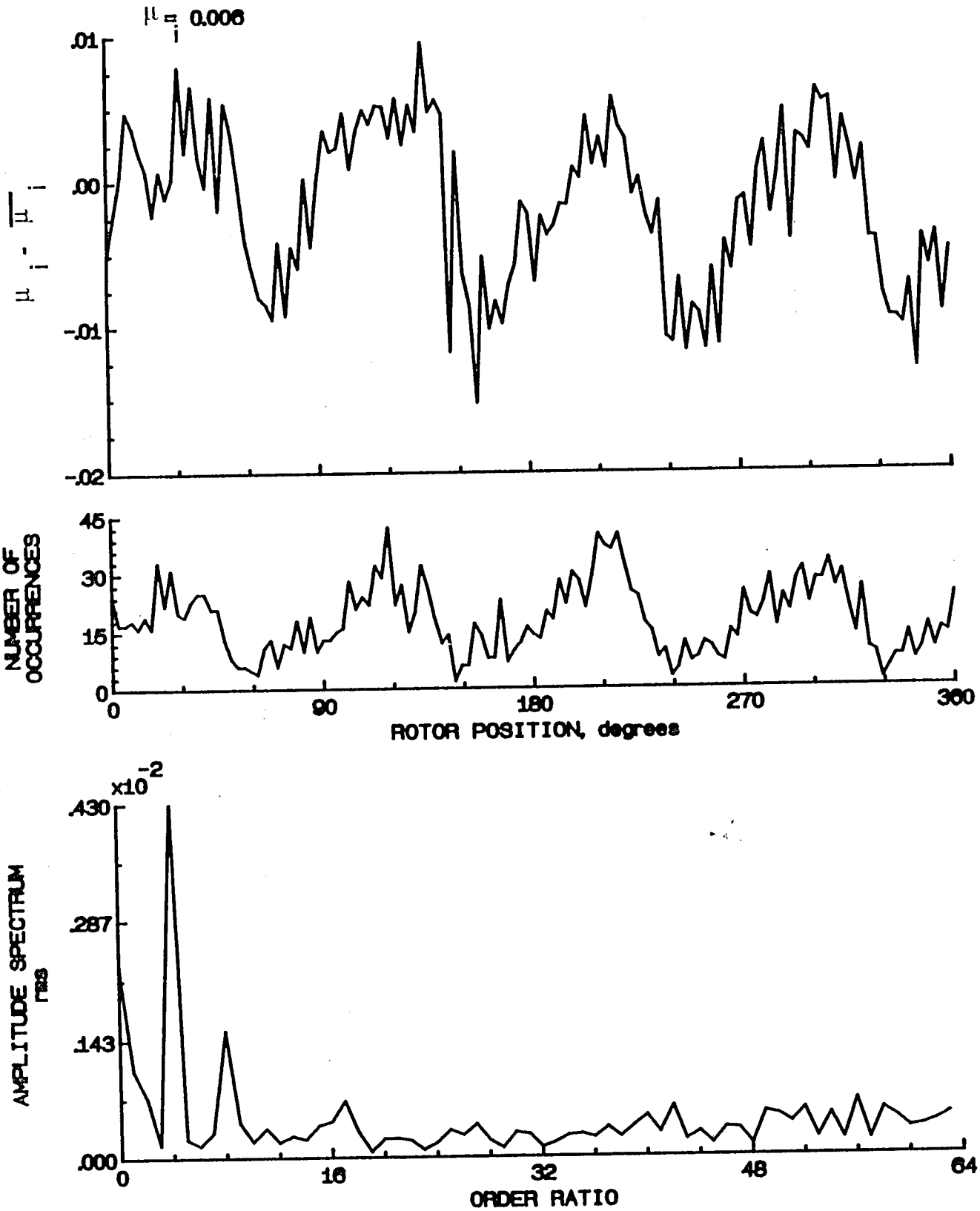
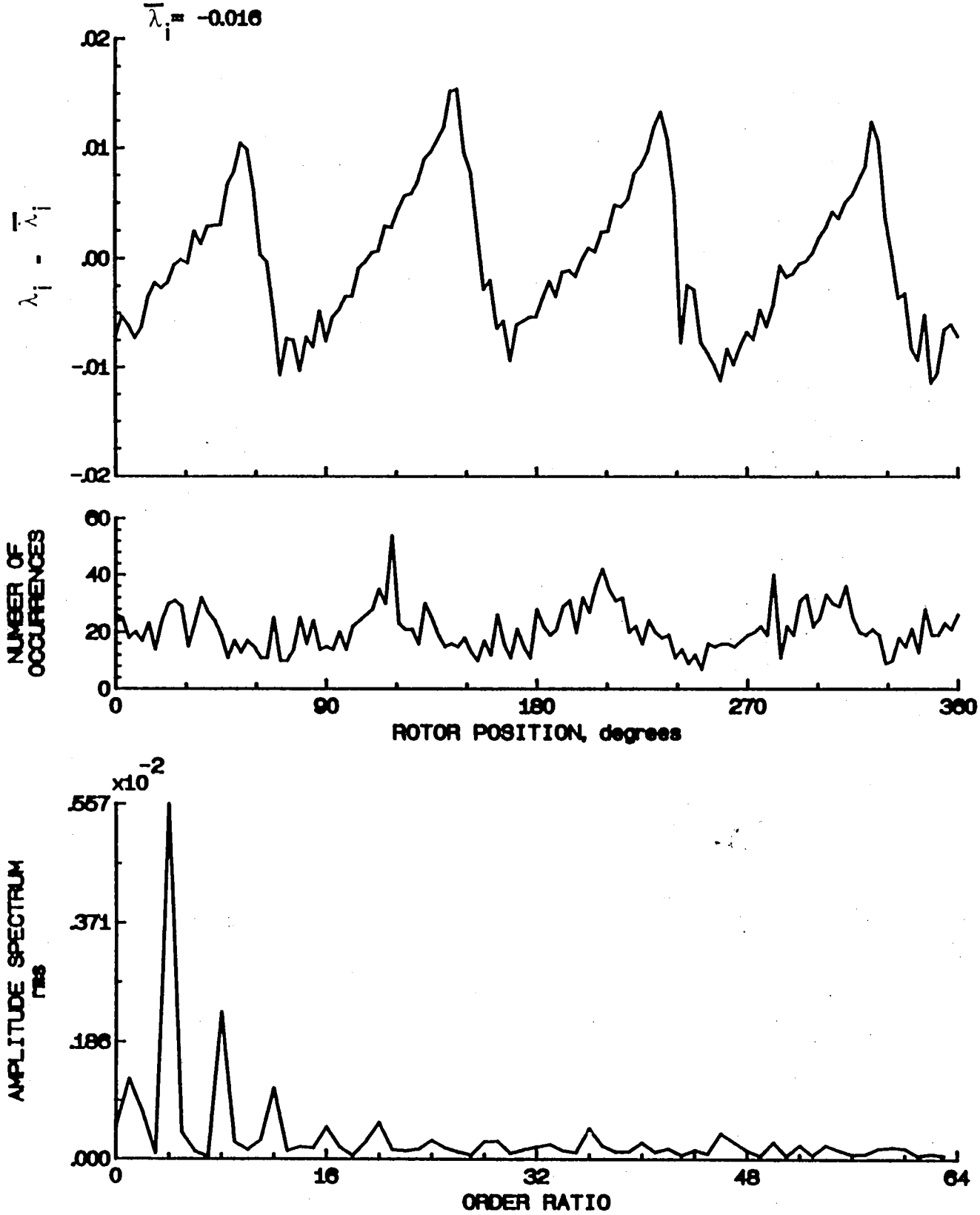


Figure 189.- Induced inflow velocity measured at 330 degrees and r/R of 0.98.



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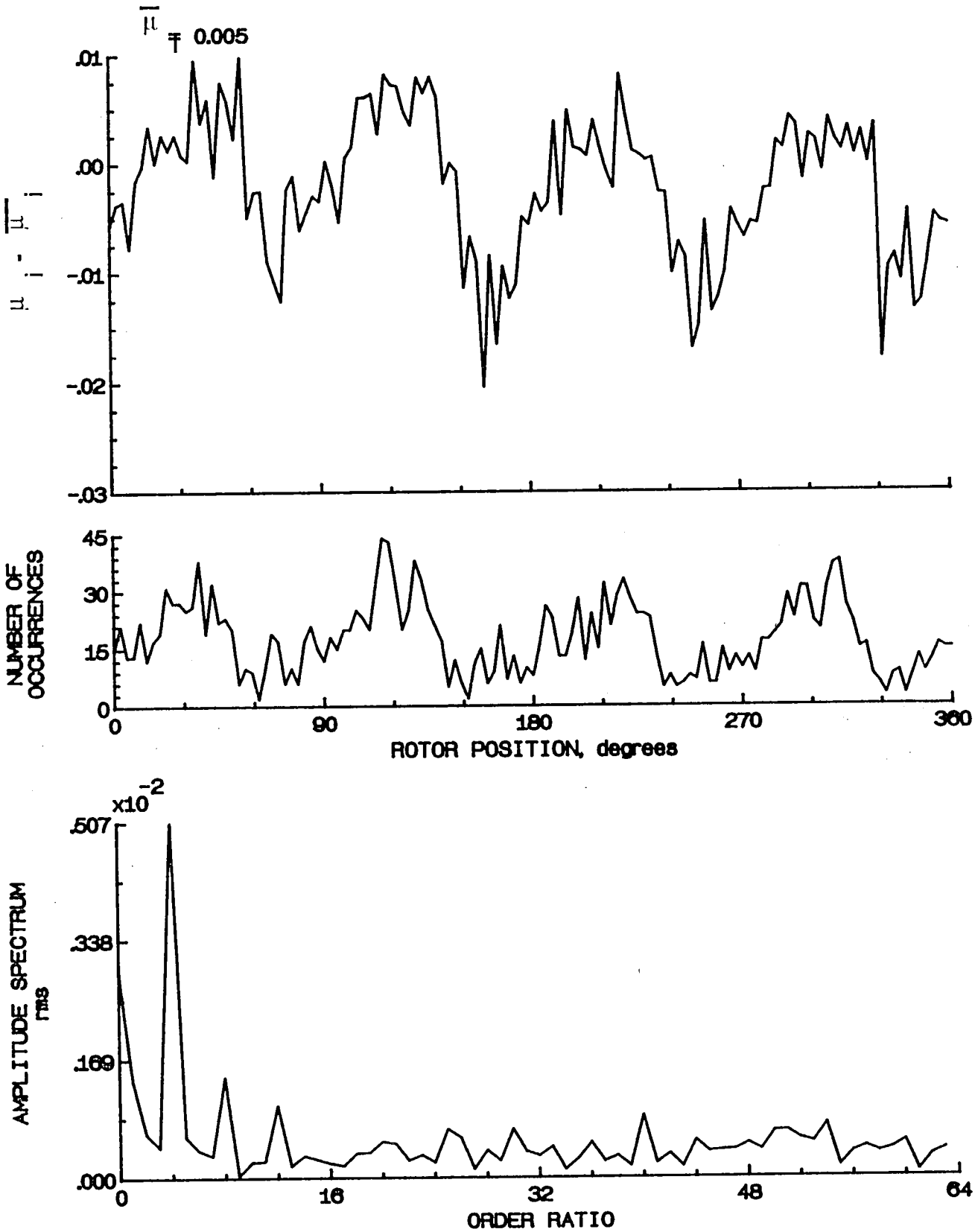
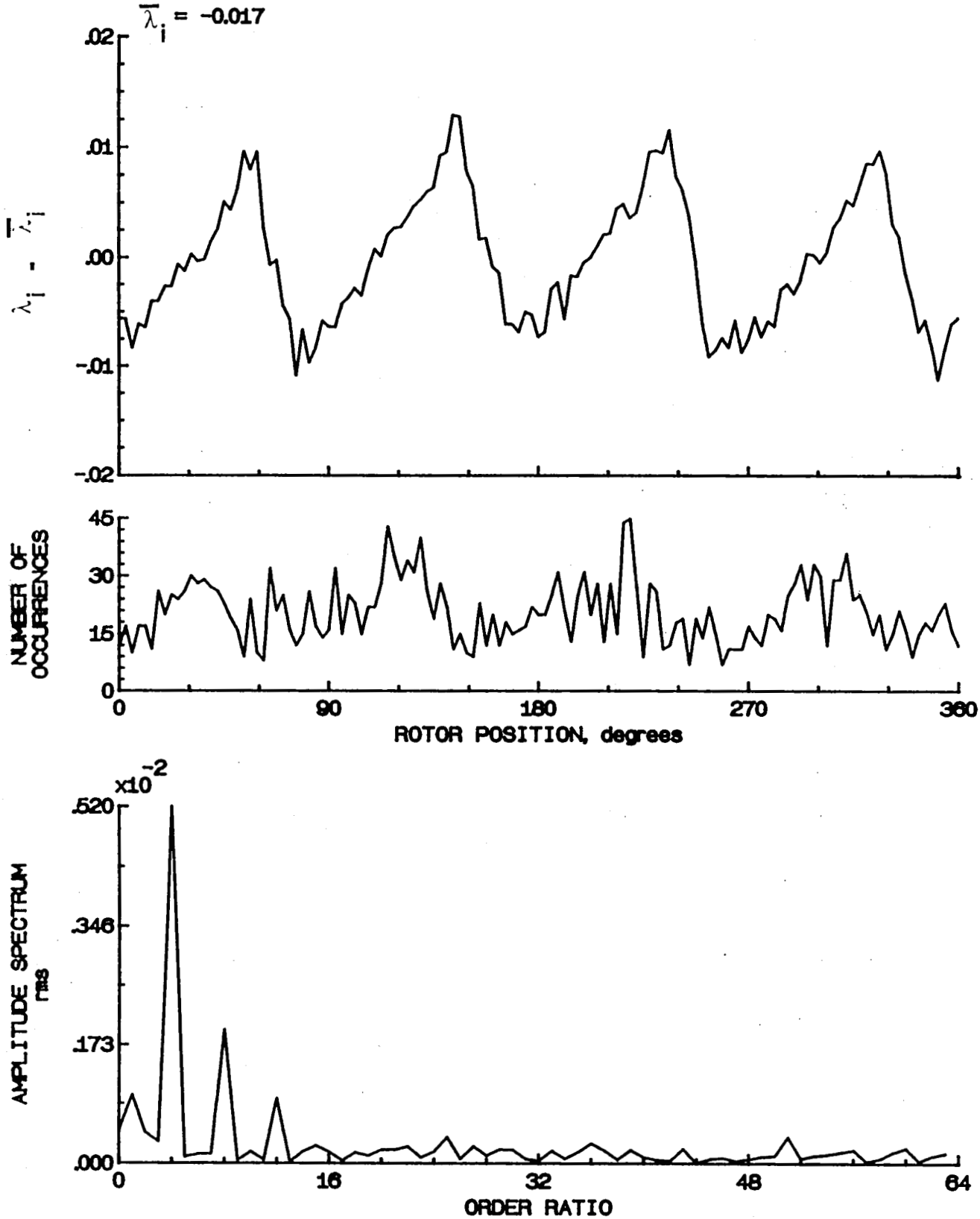


Figure 190.- Induced inflow velocity measured at 330 degrees and r/R of 1.02.



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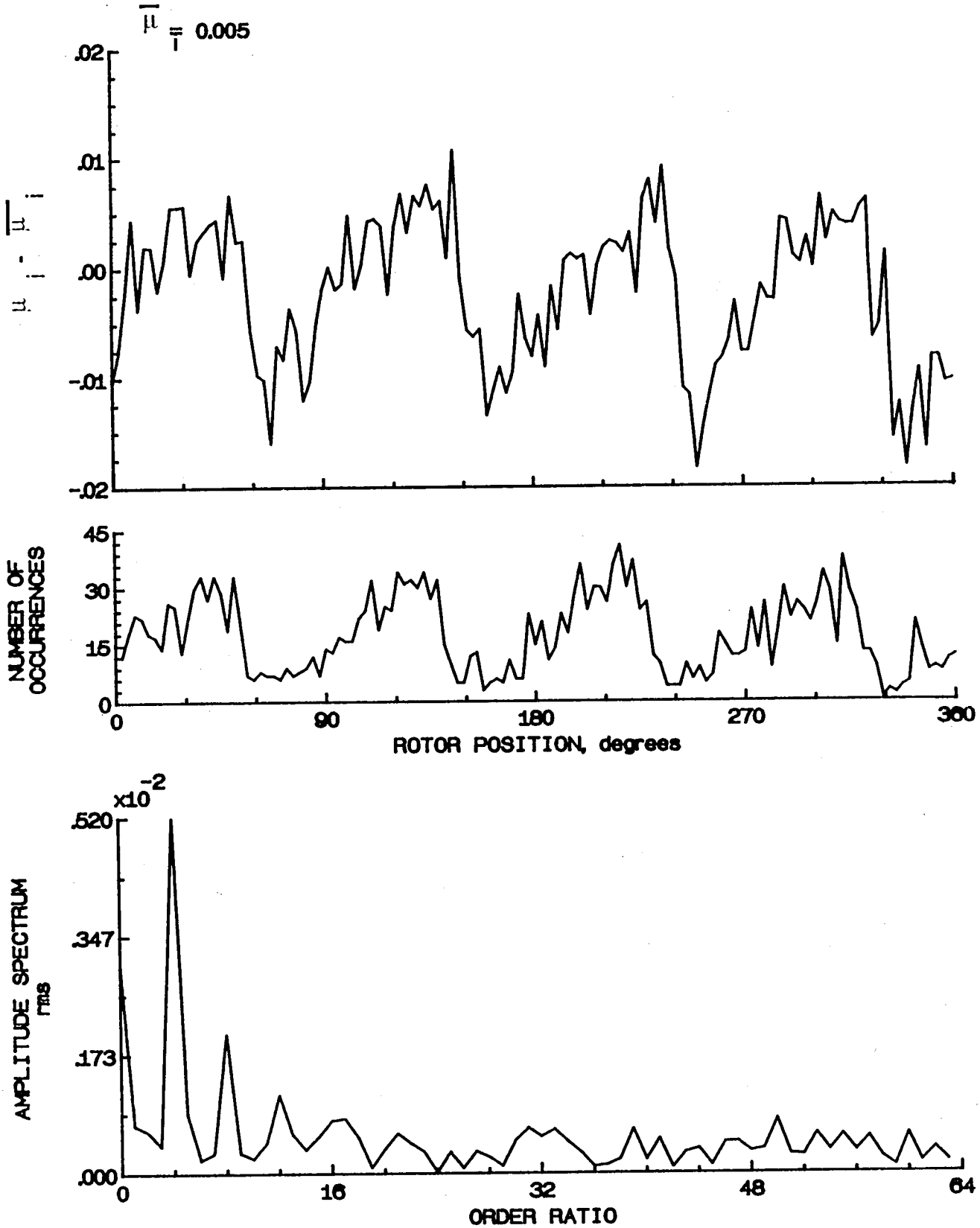
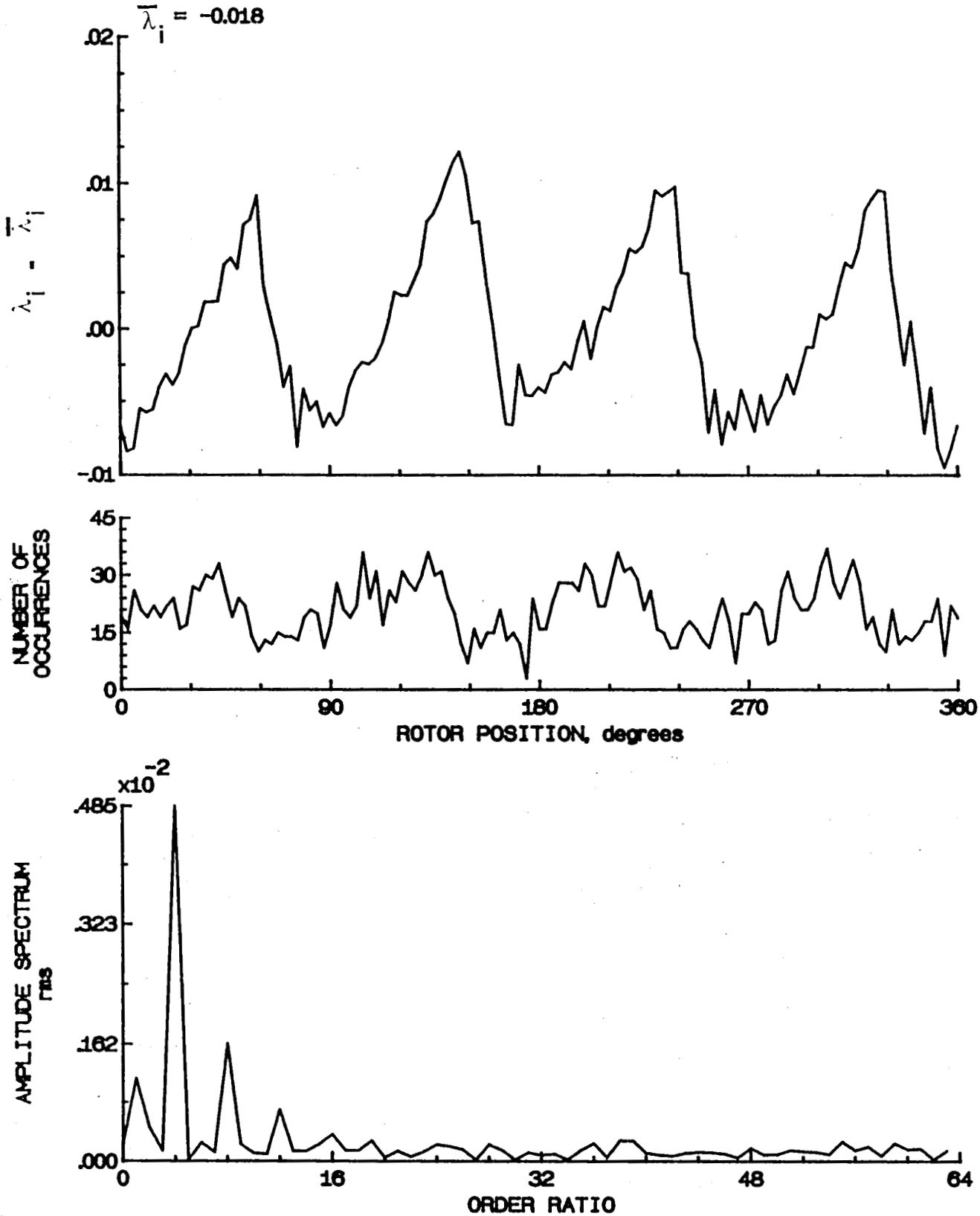


Figure 191.- Induced inflow velocity measured at 330 degrees and r/R of 1.04.



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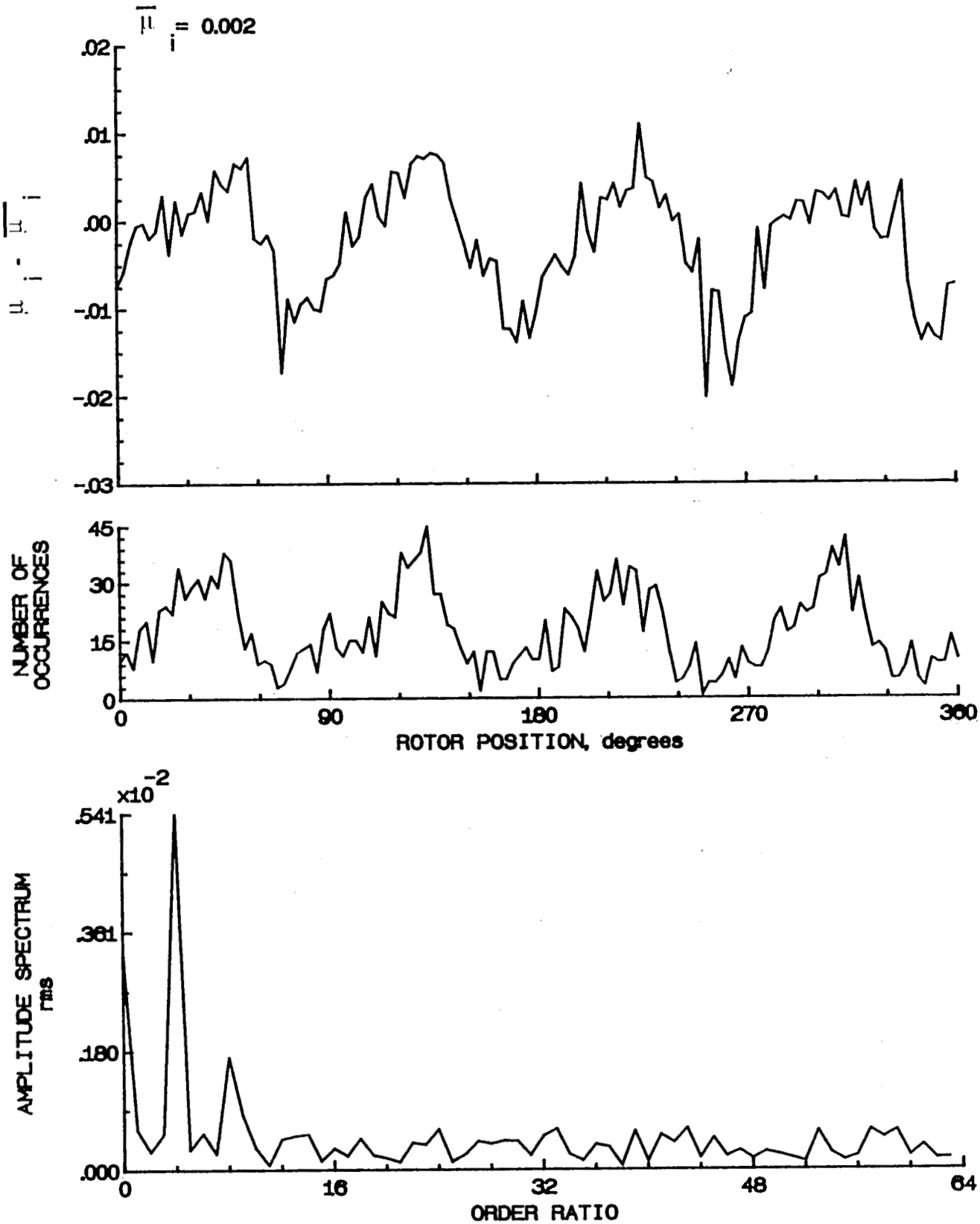

Figure 192.- Induced inflow velocity measured at 330 degrees and r/R of 1.10.

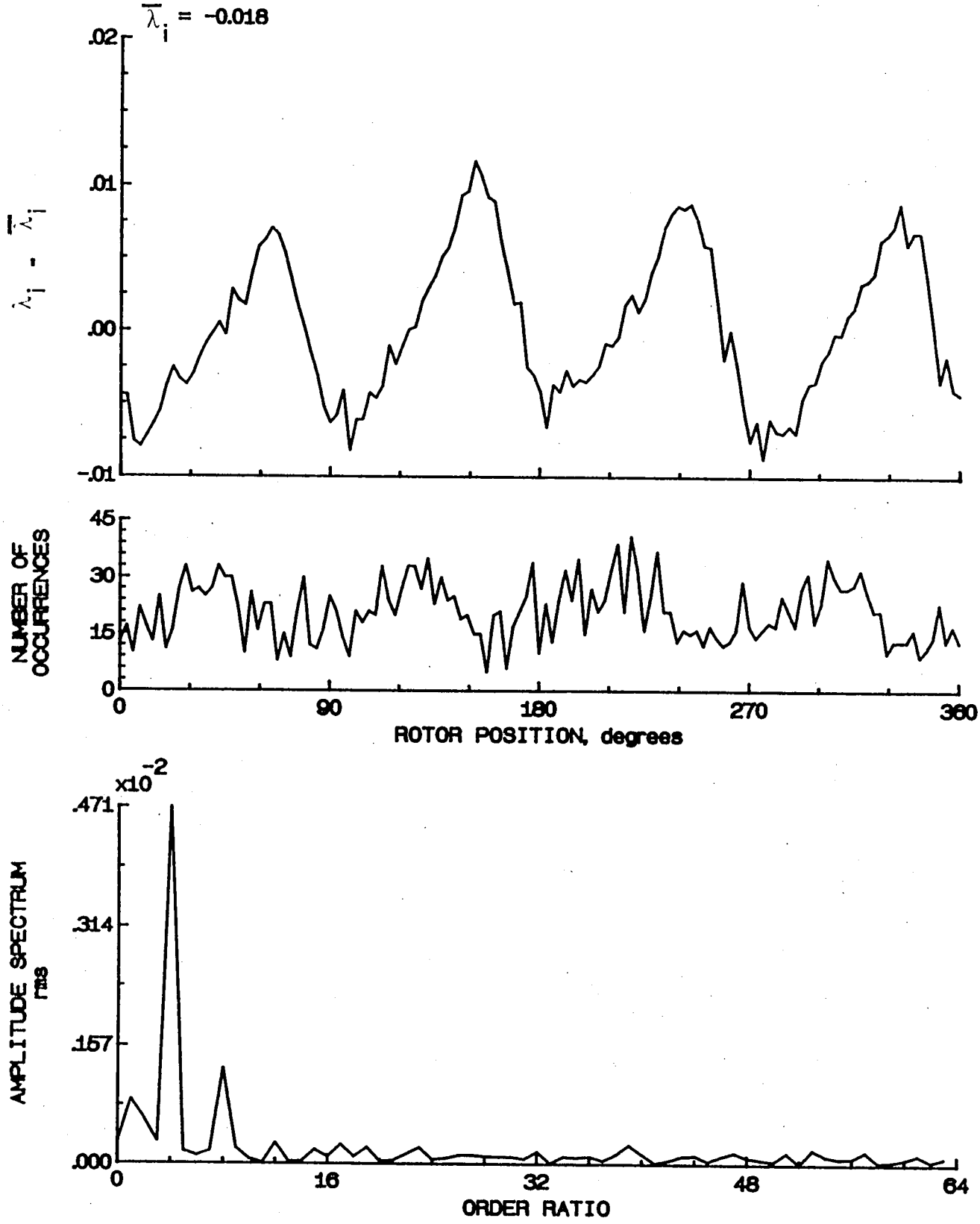

Figure 192.- Concluded.

NASA

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-102645 AVSCOM TM-90-B-010		

4. Title and Subtitle
Inflow Measurements Made With a Laser Velocimeter on a Helicopter Model in Forward Flight--Volume XI: Rectangular Planform Blades at an Advance Ratio of 0.30, 0.75 Chord Above the Tip Path Plane

5. Report Date
May 1990

6. Performing Organization Code

7. Author(s)
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Danny R. Hoad
Richard H. Sailey

8. Performing Organization Report No.

10. Work Unit No.
505-61-51-10

9. Performing Organization Name and Address
Aerostructures Directorate
USAARTA-AVSCOM
NASA Langley Research Center
Hampton, VA 23665-5225

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration, Washington, DC 20546-0001
and U.S. Army Aviation Systems Command, St. Louis, MO 63120-1798

14. Sponsoring Agency Code

15. Supplementary Notes
Susan L. Althoff, Joe W. Elliott, and Danny R. Hoad: Aerostructures Directorate, USAARTA-AVSCOM, Hampton, Virginia.
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16. Abstract
An experimental investigation was conducted in the 14- by 22-Foot Subsonic Tunnel at the NASA Langley Research Center to measure the inflow into a scale model helicopter rotor in forward flight (μ = 0.30). The measurements were made with a two-component Laser Velocimeter (LV) 0.75 chord above the plane formed by the path of the rotor tips (tip-path-plane). A conditional sampling technique was employed to determine the position of the rotor at the time that each velocity measurement was made so that the azimuthal fluctuations in velocity could be determined. Measurements were made at a total of 180 separate locations in order to clearly define the inflow character. The mean and standard deviation of the induced inflow ratios and the azimuthally dependent induced inflow ratios are included on 5.25 flexible disk in the pocket on the inside of the rear cover of this report. These data are presented herein without analysis.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Rotor Inflow Laser Velocimeter	Unclassified-Unlimited Subject Category 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	392	A17